The University of Chicago
FOUNDED BY JOHN D. ROCKEFELLER

Geology of the Onaman Iron Range Area, District of Thunder Bay, Ontario

A DISSERTATION

SUBMITTED TO THE FACULTY OF THE OGDEN GRADUATE SCHOOL OF SCIENCE IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

(DEPARTMENT OF GEOLOGY)

BY

ELWOOD S. MOORE

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GEOLOGY OF ONAMAN IRON RANGE AREA

By E S MOORE

I.—Introduction

The Onaman Iron Range area comprises about 70 square miles, lying northeast of Lake Nipigon and surrounding the head waters of the Red Paint river. It was from this stream that the area obtained its name, but the more euphonious Ojibway term, Onaman, has been substituted for the English, Red Paint. A geological survey was begun by the writer in August, 1907, according to instructions received from Mr. T. W. Gibson, Deputy Minister of Mines, but the time available proving too short for the completion of the work, a report covering a portion of the region was published[1] the following winter and the field work completed in 1908. In the above mentioned report there will be found a detailed description of the Red Paint river and some general information relating to the surrounding region, not contained in this article.

After the completion of the field work and the examination of over 200 thin sections of rocks from this region and the similar one lying along the Sturgeon river, 50 miles to the south, it is possible to give a more satisfactory and definite account of the geology of the area than was previously attempted, and in any case where the two reports differ this one is to be regarded as final. Although greater knowledge of the region has been obtained, there still remain problems which cannot yet be settled, principally because of the great metamorphism which the rocks have suffered and the thick mantle of drift, which conceals so many of the contacts.

The region has so lately been opened up that previous to the time of the survey mentioned above, no geological work had been done upon it. As a consequence of this, no mention of it is found in the literature beyond a mere reference by one of the geologists[2] of the Canadian Geological Survey who passed through this portion of the Nipigon district on a reconnaissance trip. The district, however, resembles in many respects some of the iron-bearing districts south of lake Superior, and the literature on these areas has been largely drawn upon for purposes of comparison.

During the preparation of this report much assistance has been received from various persons, and I desire to express my sincere gratitude to all those who have so generously rendered it. Special thanks are due to Messrs. W. F. Green and O. Bowles, who filled in an efficient manner the position of field assistant during the field season, and to the professors of the Geological Department of the University of Chicago, who have criticized and directed my work. To Professor Bensley, also of the University of Chicago, I am much indebted for his kindness in making some of the photomicrographs for this paper. Professor Leith of the University of Wisconsin has been good enough to offer suggestions regarding the geological relations of the district and to place at my disposal the results of some of his work. I regret that his monograph on the pre-Cambrian is not yet published, as it will contain much valuable data on the iron ranges, and throw considerable light on difficult problems connected with their origin.

II.—History of the District

The iron ranges of this district first attracted attention about the year 1904, when engineers began the survey of the National Transcontinental railway line through the region northeast of Lake Nipigon. As this line runs close to some of the outcrops, and the work connected with the surveying of it brought a number of people through this previously neglected and isolated region, considerable interest was soon manifested in the Iron formation. Shortly after the discovery of iron a number of claims were recorded by the Flaherty syndicate, and within the last two years a new iron range has

[1] 17th Rep. Bur. Min. (1908), pp. 170-189. [2] Dr. W. A. Parks, Can. Geol. Sur. Rep., Vol. XV., p. 221A.

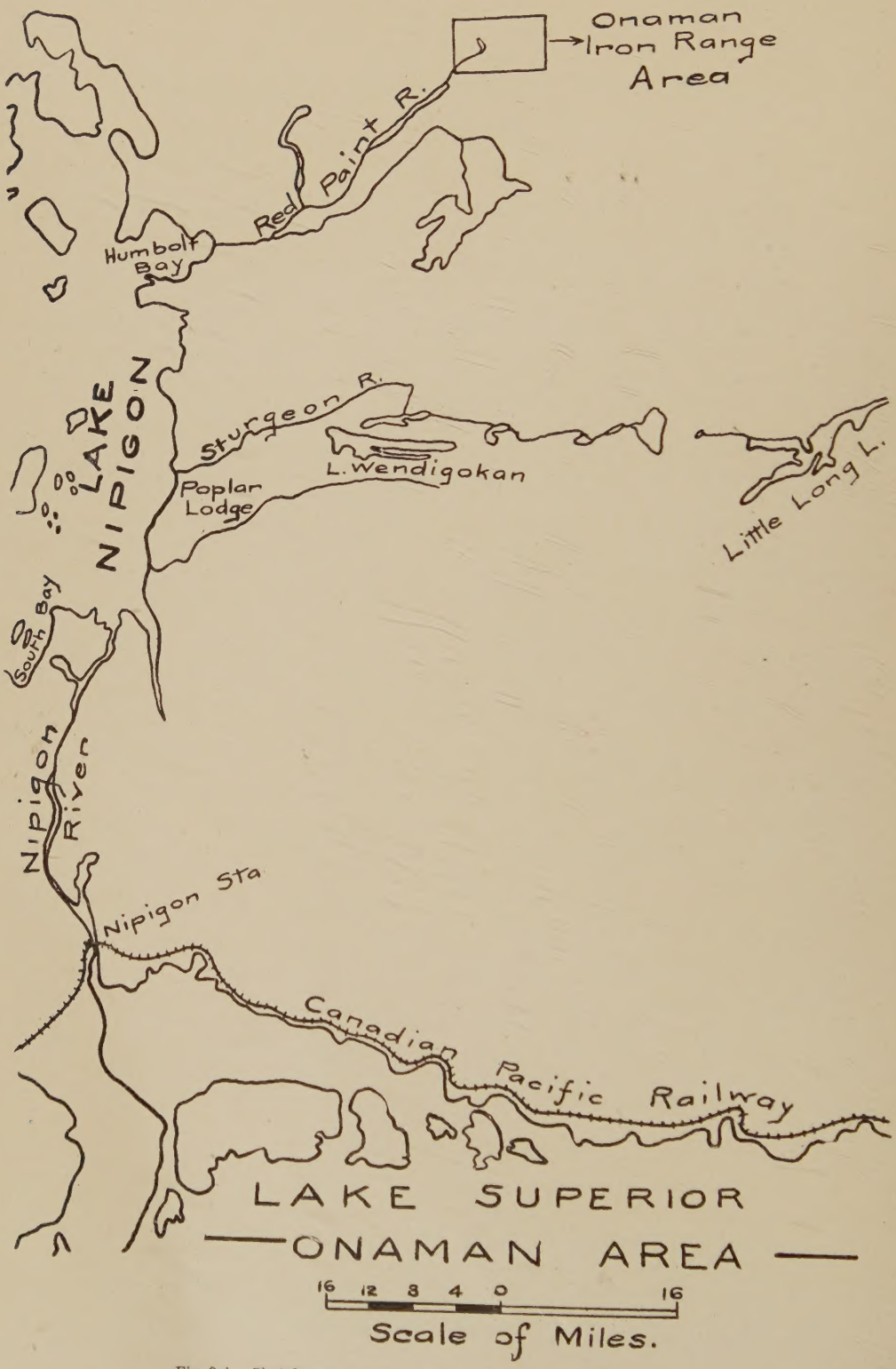

Fig. 2 A. Sketch map showing position of the Onaman Iron Range area.

been located by C. Bain, about two miles south of the first claims staked. A number of prospectors entered the field in the summer of 1906 and prospecting for iron was actively carried on, but without much success.

Since there is at present no railway within 140 miles of the iron ranges of this district, and the Iron formation does not show "pay" ore, no development work has been carried on beyond one short season of diamond drilling, and sufficient trenching and stripping to satisfy the requirements of the Ontario Mining Act. The diamond drill outfit used in the district was transported up the Red Paint river and down Johnson creek, a total distance of nearly 55 miles. The means of transport were canoes and packstraps, and there is probably not another case in the history of mining in Ontario

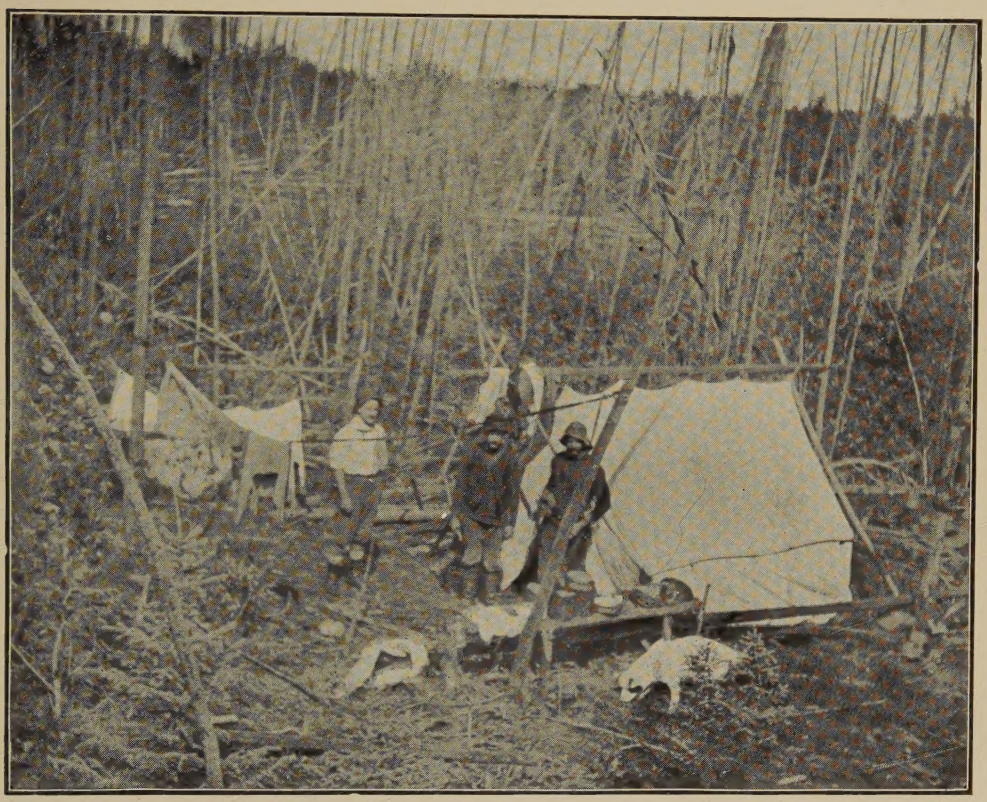

Fig. 1. Prospectors' camp on the southern iron range.

where such a feat has been accomplished. The building of the new railway, which will pass close to one of the iron ranges, will doubtless revive some of the interest previously shown in this district.

III.—Geography

Position and Extent of the District

The area under discussion lies in unsurveyed territory, within the limits of latitude 50° and 50° 30′ and longitude 87° 10′ and 87° 25′. Its long axis extends east and west across the Height of Land, the continental divide running east and west across Canada, and the western end of this axis lies about 45 miles up the Red Paint river, northeast of Lake Nipigon. (See Fig 2A.) To reach the district one leaves the main line of the Canadian Pacific railway at Nipigon village and travels to South Bay,

a little harbor at the south end of lake Nipigon, and from this point a journey of 50 miles is made to the mouth of the Red Paint river, which empties into Humbolt bay. The journey of 35 miles between the village and the lake may be made either by canoe or by a tug and tramway, which have been put into commission in connection with the construction work on the Transcontinental Railway line, and that across the lake either by canoe or steamer. The canoe trip of 50 miles from the mouth to the head waters of the Red Paint is easily made. Although there are twelve portages, the longest of them is only two-thirds of a mile, and the others are much shorter. All have well beaten trails. A good portage of one mile and a quarter crosses the divide and connects the Red Paint river with Johnson creek. The latter stream flows in the

Fig. 2. Geological party crossing Lake Nipigon by canoe.

opposite direction to the former, and for a considerable distance follows closely the iron range along the east side of the divide.

As indicated on the accompanying map, the Onaman Iron Range district includes an area about 11 miles long and 7 wide. Although this is the extent of the area mapped, there are two small areas outside of this which will be considered when discussing the geology of the district, because they are not far removed geographically from the main iron ranges and are closely related to them geologically. These areas are found at the "Red" or ninth portage on the Red Paint river, about 21 miles from its mouth, and on Ste. Marie's lake. The latter area is locally known as Trombley's claims and is situated 8 miles west of Wilgar lake, along the line of the National Transcontinental railway. Both of these areas are interesting because of the contact metamorphism exhibited in the rocks.

Climate, Soil and Vegetation

The climate in this portion of Ontario is similar to that along the continental divide in many other parts of the Province. It is characterized by cool, and, as a rule, wet summers, and very cold, dry winters. There may be frosts during every month of the year, due principally to the presence of large swamps and muskegs which retain snow and ice throughout the year and thus reduce the summer temperature in their vicinity. Cultivation and drainage of the district would largely reduce the summer frosts, but the region does not give promise of becoming an agricultural one. The soil is mostly too light for agricultural purposes, although some of the clay flats around the Height of Land and the clay plains along the lower stretches of the rivers rising in the vicinity contain soil suitable for hardy crops. Wild strawberries grow in abundance on some of these flats, and the cache-keepers at Cache 12A had a garden containing fairly good beans, lettuce, turnips, radishes and other vegetables and roots.

An abundance of rain fell during the parts of two seasons spent in the field. In 1907, which was exceptionally wet, rain fell on 22 days in July and 17 in August, and in 1908 there were 19 days with rain during the latter month. This record corresponds well with athat of many other months. The great precipitation may be due to the chilling of the warmer southerly air currents laden with moisture, by the cool air of the Hudson Bay slope.

Possibly on account of the cold climate and the nature of the soil, many trees common as far north as the northeast shore of Lake Superior and some common even in the southern portion of the Nipigon region, are not found here. No red or white pine occurs, but the more hardy evergreens flourish. The district has suffered terribly from forest fires, which in 1906 burned large areas almost bare of vegetation. Fires had also occurred during several seasons previous to this, and almost all the higher lands have been burned over, so that now they are covered with a tangled mass of dead timber, through which a new generation of trees is growing up. Great difficulty is experienced in travelling through parts of the district because of the piling up of the dead trees in the burned area, but the fact that the moss has been burned from the rocks greatly aids the geologist or prospector in search of rock outcrops.

The swamps and stream borders have escaped the fires, and so have some of the higher spots surrounded by these wet lands. In these swamps and along the streams occur the black spruce (*Picea nigra*), the white spruce (*Picea alba*), the cedar (*Thuja occidentalis*), the balsam (*Abies balsamea*) and the tamarac (*Larix americana*). On the sand plains the jack pine (*Pinus banksiana*) is especially common, and on other dry lands the poplar (*Populus tremuloides*) and white birch (*Betula papyrifera*) are plentiful. Large areas are covered with muskegs on which few trees grow, but which are covered with sphagnum moss. In these muskegs the pitcher plant is a very characteristic feature. The alder grows in thick banks along the streams and causes great annoyance to any one canoeing on small creeks.

Among small fruits, blueberries are very plentiful on the sand plains and rocky knolls and, as already mentioned, wild strawberries are found on the clay flats.

Around the Height of Land the timber is all small, but there is a general increase in size of the trees as one descends the streams from the divide. On the lower stretches of many of these streams good spruce and tamarac occur and numerous trees are suitable for lumber.

Fish and Game

The lakes and some of the streams abound with fish. The lakes contain pike in largest numbers and pickerel and whitefish to a lesser extent, while in some of the streams pike and brook trout are plentiful. Among the large land animals the moose, the caribou, and the bear were seen, but no red deer. The latter animal seems to be scarce in all of the Nipigon region, and probably because of its scarcity, wolves are

not so numerous as they are in many other parts of northern Ontario. The small fur-bearing animals are trapped in large numbers during the winter, and among these are mink, marten, muskrat and fisher. The beaver is quite common and the houses, dams, trails and cuttings of this animal were seen in many places. The first flying squirrel which the writer has seen in northern Ontario, was observed in this region.

Among game birds, the partridge and Canadian grouse are plentiful, and some men familiar with the region state that the latter bird often appears in large numbers about the time the snow begins to disappear in the spring. They are then seen feeding on the buds of the bushes along the streams.

Fig. 3. Typical brulé, southern iron range.

Surveys

Since this district lies in unsurveyed territory, the chained try-line of the Trans-continental railway proved to be of great service in the preparation of the geological map accompanying this report. Some of the mining claims had been staked out by use of a dial compass, and in that case were quite accurately outlined and have been placed on the map, while others were so badly laid out, on account of the deflection of the compass, that they were of no service in our field work.

This surveyed railway line was used as a base to which the work was tied, but as it did not represent the final line for the railroad it has not been placed on the map. Off-sets were made from the line across the Iron formation outcrops at intervals of 100 to 300 feet, depending upon the complexity of the geological structures. Where the Iron formation was out of reach of the railway line, as in the southern range, a picket

line was run along the range and off-sets made from it. To locate the outcrops near the north and south borders of the map and at some distance from the iron range, north and south lines one mile apart were run by compass and paced to the border of the area, and other lines were run between the first ones mentioned, well out towards the border. The work was checked by running these lines in the form of three sides of a rectangle and always returning to the base line to tie in. As an ordinary compass could not be depended upon over the greater part of the region, the dial was used almost entirely.

IV.—Physiography

Under this head will be considered (1) the topography and (2) the drainage of the district. Under topography, the three items, the ancient peneplains, the influence of the rocks on topography, and the topography of the drift will be taken up in order.

Fig. 4. Kettle lake in foreground and regular outline of Keewatin hills in the distance.

Topography

The Onaman area was a portion of the great post-Laurentian and pre-Huronian peneplain. Evidence of this is found in the remnants of this old plain underlying the basal conglomerate of the Lower Huronian in surrounding areas, and in the rocks which make up that basal conglomerate. It has been pointed out by Wilson[3] that a peneplanation also followed the folding of the Huronian, and that the Keweenawan and Cretaceous periods were both followed by great periods of erosion, which developed peneplains in the northeastern portion of our continent. That the area under consideration was concerned in all these changes, and that it must have been several times elevated

[3]A. W. G. Wilson, The Laurentian Peneplain, Jour. of Geol., Vol. XI., 1903.

is shown in the relations of this area to those surfaces overlying the Keweenawan and the Cretaceous rocks in surrounding regions. We have no evidence that since Cretaceous time this region has suffered much change in level, but it has probably been subject to continuous erosion which has so thoroughly worn away the hills that the present surface may be regarded as a characteristic peneplain. The amount of material removed since Keewatin time must have been enormous, as we have no direct evidence that this region has been submerged, and it would appear that some area in this portion of the Archean shield was supplying clastics to the surrounding seas almost constantly after Laurentian time. This great erosion is probably responsible for the fact that the synclines of Keewatin rocks, and particularly the Iron formation, are so shallow and narrow in this northern region.

Fig. 5. Kettle lakes in terminal moraine on Johnson creek.

The present surface is dotted with numerous rounded hills of Keewatin and Laurentian rocks rising through the drift, but none of them have any great elevation above the general level. The altitude of the highest hills in the area mapped is not more than 1,150 feet, while that of the bottoms of the deepest valleys is over 1,000 feet. The surface is very rough, but the relief is low and in all directions one sees for many miles, hills rising to the same general level, and on account of the drift filling many of the valleys the surface of the district is brought nearer a plane (See Fig. 4.) As the highest hills in this area correspond pretty closely in elevation with those of the Keweenawan diabase in the vicinity of lake Nipigon, they appear to represent the remnants of the Cretaceous base-level. In the district covered by the diabase the contours are much more irregular than they are in the Archean region, and the rivers in some places have gorges 400 feet deep where they descend from lake Nipigon to lake

Superior. These deep gorges seem to be due, however, to the streams following new channels because their old valleys have been blocked with glacial drift. Towards the northeast, the peneplain grades down into the coastal plain of the James Bay slope.

The region has been so thoroughly peneplained that the several rock formations have not exerted, on account of varying qualities of resistance, any great influence on the topography of the district as a whole. The greenstones may occur under swamps or in the highest hills. The hard jaspers which have retained a glassy polish since Pleistocene time may have the lowest outcrops of any of the rocks, and while the rhyolites usually form hills, their white color on the weathered surface makes them unduly conspicuous, and one is liable to overestimate their height when looking over the region. The Keweenawan diabases have eroded readily, and the dikes have been worn away as rapidly as the surrounding rocks.

The drift is thick over parts of this area and since the forest fires have denuded it of trees, its topographic features stand out clearly. Its topography is in a youthful stage of development, as the ridges are sharp and many comparatively deep undrained depressions exist. Almost every phase of drift topography is found, from that of the ground moraine with almost level surface, now covered with swamps or muskegs and broken only by small knolls of drift, to the terminal moraines with deep undrained depressions and irregular hills. (Figs. 5, 21 and 22.) Some of these depressions contain lakes, while others are dry and the bottoms of them are as much as 80 feet below the tops of the hills surrounding the basin. Besides the kettle lakes still in existence, there are local clay flats with small streams cutting very youthful gulleys across them, and these areas bear evidence of having been covered by small lakes in the drift, which have since been drained. Eskers and kames are not prominent, although two small examples of the former and a few of the latter were seen. Small outwash plains occur in front of the terminal moraines. The irregular topography around the Height of Land gives place, as one descends the streams leading from it, to plains of sand and clay formed in the shallow waters of the large glacial lakes, Algonquin on the west side of the divide, and Ojibway[4] on the east.

Drainage

Two streams of considerable volume rise in this district and control its drainage. These are Johnson creek with several tributaries, two of which, the McCrey and Jeffries creeks are important; and the Red Paint river, which has very few tributaries in the Onaman district, but receives several large ones lower down in its course. The former stream rises in a large muskeg saturated with water, and the latter originates in Red Paint lake, a beautifully blue lake, fed by calcareous springs issuing from the drift. They flow in opposite directions and represent the drainage of the Hudson Bay basin and that of the St. Lawrence River basin on either side of the Height of Land. In some places this divide is so inconspicuous that one can travel across it in a swamp from which water issues in opposite directions, and in other places it is represented by a distinct ridge of drift or solid rock. The region, as a whole, is characterized by a great number of swamps and muskegs which are a serious impediment to travel in the wet seasons. The rivers have broad, shallow valleys and meandering courses.

V.—Geology

Outline of the Historical Geology

The rocks of this area may be classified as in the following table. The greenstones, being the oldest, are placed at the base, and the others are arranged in order of their

[4] See Dr. Coleman's paper on Lake Ojibway in this volume.

relative ages. The age of the diorites is not fixed beyond the fact that they are post-Laurentian, and therefore they are placed apart in the classification.

CENOZOIC
- Recent,—Alluvial deposits and travertine.
- Pleistocene,—Drift and lacustrine sands, silts and clays.

PRE-CAMBRIAN
- Keweenawan,—Diabase (dikes).
  (Igneous contact.)
- Huronian,—Hornblende-porphyry (small intrusive masses.)
  (Igneous contact.)
- Laurentian,—Granite and granite-gneiss (batholiths).
  (Igneous contact.)
- Keewatin
  - Iron formation.
  - Rhyolite-tuff, agglomerate and conglomerate.
  - Rhyolite, rhyolite-porphyry and feldspar-porphyry.
  - Greenstones and green schists.
- Post-Laurentian,—Diorite dikes.

The geological history of the district begins with the formation of the greenstones, which occupy a very prominent place here, as in almost all other Keewatin areas. On account of their great age and consequent metamorphism, they are now dark to light green from the presence of chlorite, and are often so altered that their original mineral composition cannot be determined. Thus the term greenstone seems to be appropriate for them. A detailed examination shows, however, that they are made up of a complex of basic igneous rocks composed of two types, extrusive and intrusive; the former being characterized by their fine-grained texture and pillow or ellipsoidal structure, and the latter by their granular texture. The only typical extrusive structure observed in this region is the pillow or ellipsoidal structure, which is well developed over considerable areas.

The composition of at least some of the extrusives is that of diabase. The intrusives are represented by greatly weathered gabbros, coarse diabases, augite porphyries and probably other basic rocks. These represent the rocks which formed at depths possibly contemporaneous with the extrusives and which have, in places, been exposed by erosion. From these massive rocks green chloritic schists have been developed by dynamo-regional metamorphism. It is possible that some of these schists have been developed from sediments, but such an origin cannot be established for them.

Following the period when the basic rocks were the predominant product of vulcanism, there was a period when the acid rocks were the prevailing type. It is probable that during the time that the basic rocks were being most prominently formed, some acid rocks also originated, but it is clear that there were periods in which first one and then the other was largely predominant. There are patches of rhyolite here and there in great masses of greenstone, and they are so intimately folded together that their relations cannot be defined, but it is certain that the acid rocks in many places cut the greenstones, and in no case observed do the greenstones cut the acid rocks. Some of the latter rocks are regarded as later than the Iron formation, but none of the greenstones have been so recognized.

So far as can be gathered from the field and laboratory study of these acid rocks, they are largely extrusive in origin. This is shown by their fine-grained groundmass, with very few and small phenocrysts which are often well rounded or eaten into by the absorptive action of the groundmass, possibly upon relief from pressure when the rock reached the surface. The phenocrysts are often broken and the spaces between the fragments are filled with the groundmass, as if these had been broken during the movements of the lava. Another evidence of their extrusive character is the fact that they are associated with tuffs, which grade into sedimentary rocks, in such a way that rhyolite

forms the cement of the tuff fragments in a few places, and almost everywhere the tuff overlies the acid rocks. That these rocks are not intrusive into the Iron formation, except in one case, is shown by outcrops of them in the Iron formation where they are always surrounded by a zone of tuffs, showing that they have been folded in from beneath, with the sediment above them. The outcrop of the rhyolite also conforms with the structure of the Iron formation, in that it has the same strike and dip and never cuts across the bands. There is no evidence that extrusive sheets of rhyolite have been interbedded with the Iron formation. It is probable, however, that in some parts of the district volcanic activity continued, because there is a large mass of rhyolite and rhyolite-porphyry cutting off the eastern end of the northern iron range in such a way that it must be considered later than the Iron formation.

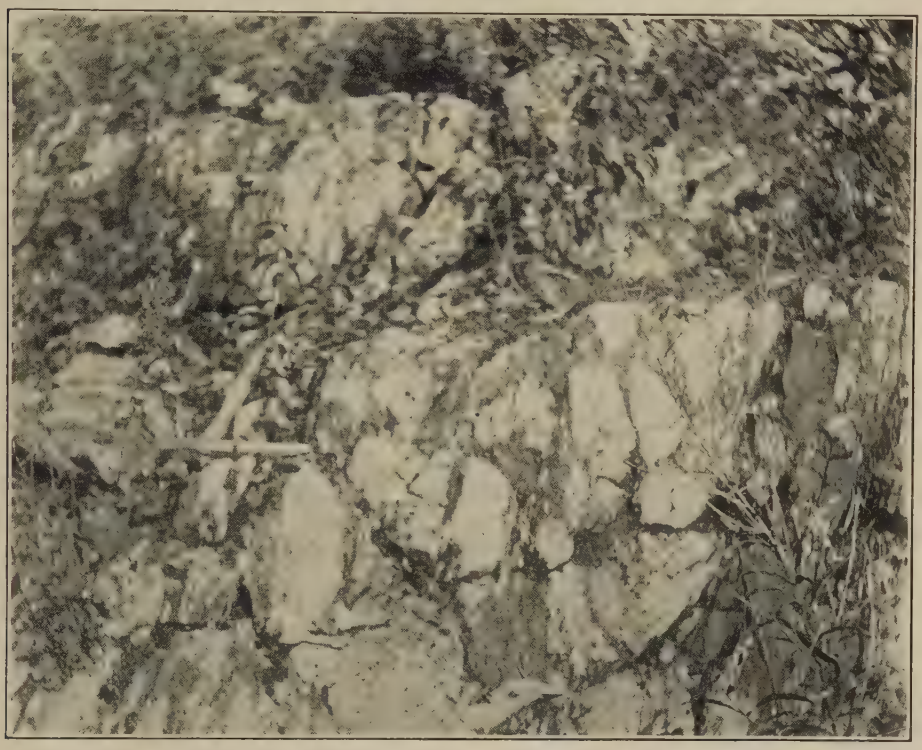

Fig. 6. Agglomerate at the twelfth portage on the Red Paint river, below Holliday lake.

Accompanying the rhyolite, but for the most part a little later than it, there is a series of pyroclastics grading into true sediments. They are composed of tuffs grading through agglomerates or distinctly angular, coarse fragments with a sedimentary matrix, to a rock with the pebbles sufficiently waterworn to be called a conglomerate. The angular type of fragment is, however, largely predominant, and these fragments represent the results of the explosive phase of volcanic activity. (Fig. 6.)

Above the pyroclastics, the Iron formation, consisting of sedimentary deposits, was laid down. In one place a few pebbles or tuff fragments were found lying in a slate near the base of the Iron formation and between narrow bands of jasper. In another place there is evidence that a band of tuff with a sedimentary matrix had been deposited with the Iron formation, as it is difficult to explain the presence of this band on any other supposition. This band may indicate either volcanic activity during the deposition of the Iron formation, or the transportation of a small amount of coarse

material from the surrounding lands where it had previously been deposited by volcanic action.

It is the writer's opinion that the Iron formation was deposited in lakes, some of which were of large size. The reasons for holding this opinion are as follows: (1) The very irregular surface which would be developed during such a great period of igneous activity as that which characterized the Keewatin, would be conducive to the formation of enclosed basins which would tend to increase in depth as the rocks adjusted themselves during the transfer of material from below upward. (2) That there was poor drainage is shown by the lack everywhere in the Keewatin of coarse sediments well water-worn, but that there was weathering action and transportation of materials going on all the time, is evident from the presence of slates of distinctly clastic origin and of graywackés, which grade into fine slates and occur as narrow bands interbedded with jaspers and magnetites. (3) It is clear that land surfaces must have been in the vicinity to supply the above mentioned clastic deposits, always found in the Iron formation. If one considers the distribution of the Keewatin iron ranges in Canada, it is difficult to conceive of the sea covering all the area over which these ranges have been formed, and at the same time leaving sufficient land exposed to supply the clastics. (4) The difficulty of saturating the ocean with iron salts would be obviated and a geological condition more nearly like some conditions existing on the earth at the present time could be postulated.

As time passed, the mountain building thrusts seem to have folded the Keewatin sediments into close folds with their long axes running in a general east and west to northeast and southwest direction. Beneath the anticlines of these folds, the great granite batholiths had a tendency to rise and form the Laurentian granite and gneiss masses so widespread in the Archean of Canada. On the accompanying map it will be observed that the two outcrops of granite and gneiss represented there occur between synclines in the Keewatin sediments.

The forces which folded the sediments, in many places mashed the igneous rocks into distinct schists, with their plane of schistosity as a rule nearly vertical.

After the folding of the Keewatin, the intrusion of the Laurentian, and the consequent metamorphism developed by this intrusion, a great peneplanation began and affected all of the Keewatin-Laurentian shield. During this peneplanation the basal conglomerate of the Huronian was developed, and it includes pebbles of all types of older rocks found within many miles of the point where it was laid down. This rock was not found in the Onaman area, possibly because the continental divide has always been near this region, and very little of the conglomerate was formed here, or because it was formed and since worn away and the materials carried to lower levels. It is well developed along the Sturgeon river, about 45 miles south of this area, and it is probable that this is a portion of a large deposit made in the Nipigon basin during Huronian time. There is evidence of the existence of this basin at an early date, in the presence of the great Keweenawan deposits which filled it, and the remnants of older quartzite and some ancient limestone.

Since the formation of the above mentioned peneplain, we have a rather meagre history of the district. There was a little volcanic activity during the Huronian, as shown by the presence of hornblende-porphyries occurring in small irregular masses which cut the Iron formation, and are themselves cut by the Keweenawan diabase dikes. Two diorite dikes also cut the Iron formation on the Height of Land claims, but beyond the fact that they are post-Laurentian and possibly related to the hornblende-porphyry, nothing can be said about their time of origin.

In the Keweenawan period the great igneous activity of the Lake Superior and Lake Nipigon basins extended as far northeast as the region under discussion. Here there are large diabase dikes running for miles across the country, with persistent strike, and cutting all earlier formations regardless of their nature. There are no

remnants of sheets or sills which would make it appear that these dikes served as channels through which material ascended to form such masses, as similar dikes have served in some other parts of the Nipigon region. As these dikes run in an approximate northwest-southeast direction, and roughly parallel to the lake Nipigon basin, where there was such extensive volcanic activity, it is very probable that the adjustment of the rocks around the basin caused the fissures which became filled from the main diabase magma.

From Keweenawan time until the Pleistocene, there is a lost chapter in the geological history of this area, except what can be read from the results of great periods of erosion in the surrounding rocks. If any rocks were formed here they have since been entirely eroded away. It seems probable that during this time erosion was in progress, continuously, and a Cretaceous peneplain was the result.

In the Pleistocene period the glacier halted here for a long time and left extensive terminal moraines and their accompanying structures. That the ice remained until after lake Algonquin began to subside from its highest level is shown by the absence of beaches or water action on the morainic deposits, while the lake is known to have reached a level higher than that occupied by these deposits, and lake beds can be traced up the Red Paint river to their base. It is therefore evident that the ice formed the northern shore of the lake when it reached its greatest extension.

The only recent deposit of interest is the travertine which is being deposited in and around Red Paint lake and along the stream leading from it. This mineral comes from springs which feed the lake, and arise in the drift from which the calcium carbonate is derived.

Structure

Under this heading will be considered (1) rock relationships, or the structural relations of the several rock formations to one another; (2) folding; (3) faulting; (4) cleavage; (5) fracture. The sections on the accompanying map will give the reader some idea of the general rock structure of the district.

Rock Relationships:—The rock relationships here are extremely complicated because of metamorphism, because of the great predominance of igneous rock, and the occurrence of both intrusive and extrusive types. The greenstones consist of deep-seated intrusive rocks, overlain by and intruding into surface flows, and they have again been intruded and overflowed by acid rocks in the form of dikes, bosses, irregular masses, and flows. The consolidated stratified rocks of the region are the thin beds of pyroclastics, which have been in part worked over by water, and the Iron formation. These have in one place been cut through and overflowed by acid eruptives, and later, in Laurentian time, the batholiths of granite which seem to have accompanied the folding at the close of the Keewatin, cut through all the earlier rocks. Some of the Keewatin rocks, including the Iron formation, were, about Huronian time, cut by dikes and irregular masses of rock of medium composition, and in Keweenawan time the diabase dikes cut all earlier rocks, and, in some spots, in an intricate manner. The drift was then deposited over all these during the Pleistocene period.

Folding:—Folding occurred on a large scale about the end of the Keewatin period, and two synclines, which represent the minor portions of much larger synclines, are represented by the iron ranges. There seems to have been a tendency for the synclines to develop at the junction between the chief rhyolite and greenstone masses, probably because of a line of weakness there, and of an original depression which would be emphasized during the folding.

There has been extensive folding in some parts of the Nipigon region since Huronian time, and evidences of it may be seen in the folding and mashing of the Huronian conglomerate in the Lake Wendigokan region, on the east side of lake Nipigon. The

post-Huronian folding was not so extensive, however, as that of the post-Keewatin, as there are areas in Ontario where the Huronian is almost undisturbed, but in no place, so far as reported, has the Keewatin been found without intense metamorphism.

That the greater thrusts occurred before the solidification of the Laurentian granite is evident from the facts that this rock is not folded into the same great regular anticlines and synclines as the Keewatin rocks, and is not mashed to nearly the same extent, but has its greatest schistosity developed around the periphery of the batholiths, while the central portion may often be almost non-schistose. To what extent the eruption of the granite was the cause of the folding or the result of it, cannot be decided, but on account of the relations between the granite and the anticlines of the folds, it is probable that the former rose beneath the latter as warping took place, as it appears to have done in more modern mountain building.

Fig. 7.—Folding and fracturing in the Iron formation of the southern range.

The thrusts producing the major folding were from nearly north and south, judging from the general east and west strike of the axes of these folds. The sediments were closely folded, so that their bedding planes now stand almost vertical, but their dip varies greatly because of the presence of large masses of igneous rock, which produce, on account of superior resistance to folding stresses, local irregularities in the folds of the sediments. The dips run from 55° to 90°, with 70° northward as a common occurrence. Where the dips are less than 90° they must be regarded as those of overturned folds, and in the case of the 55° dip, the fold has been overturned to the extent of 35°. (See structure section on accompanying map.)

Superimposed on the major folds are many minor folds and crumplings, varying even to microscopic size (Fig. 1, Plate 1). The result of the combination of major and minor folds is an extremely complicated structure, and it is impossible to work out

with any degree of satisfaction the thickness of the Iron formation, as beds are often repeated in the most irregular manner. The distinction between some of the rock formations has to be made entirely on a lithological basis.

That the folding occurred when the sedimentary rocks were, in most cases, not deeply buried, is evident from the fractured condition of many of the rocks, a good example of which is seen in Fig. 7, and that some minor folding occurred within the zone of flow is illustrated in Fig. 8. This condition was observed on the Miller claims, and it shows a thickening of the beds in the apex of the anticlines and a thinning of them along the limbs. The more brittle jasper bands have been entirely pinched off in the limbs and thickened in the apex of the anticline, while the slates enclosing the jasper bands, being in the zone of flow for slate and more plastic than the jasper, have thinned and thickened without leaving any trace of the dragging which must have occurred during the process. This folding occurred in a horizontal plane normal to the plane of schistosity common to the region, and it is only tributary to the major folding produced by the forces which developed the schistosity.

Faulting:—A number of faults were observed in the region, and they were all of the normal type. On the Winter Camp claims two fault planes were seen, which repre-

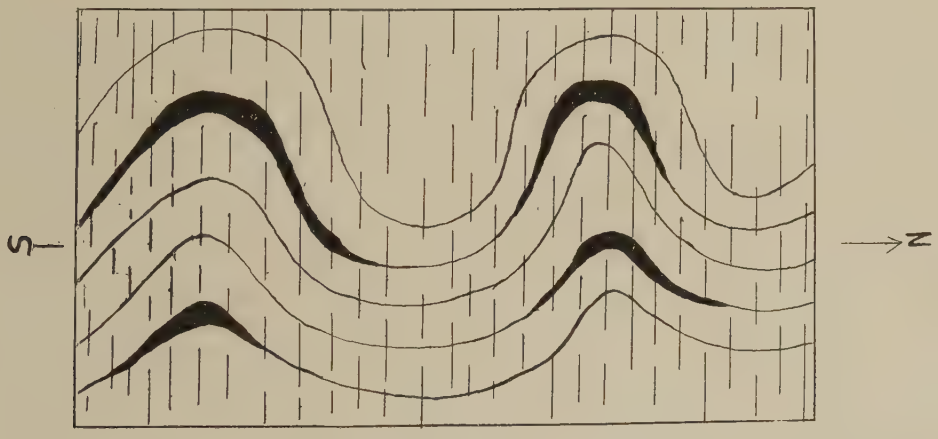

Fig. 8.—Sketch made in the field to illustrate the thickening and thinning of the beds in a minor fold, formed in the zone of flow. Black represents jasper bands in bands of slate. The schistosity is normal to the bedding planes.

sent the most extensive faults of the area. At this point a large block of ellipsoidal greenstone had risen through the Iron formation. The evidences of faulting were distinctly seen in the brecciation of the jasper, and the slickensided surfaces still remaining on the hard jasper.

Connected with the movements and brecciation, there appears to have been deposition of pyrite from solution. This may be seen everywhere as little veins penetrating the greenstone and jasper. The fault plane on the north side of the block appears to be nearly vertical, and information obtained from a drill hole put down at an inclination of 60° to the vertical shows that the dip of the plane is at least 65°, because the hole failed to reach the greenstone at 351 feet, although the distance on the surface of the ground between the drill hole and the greenstone is only 300 feet.

A number of small faults, some of which are indicated on the map, occur in the southern iron range, and they are all either of the dip or oblique type. They are not of great extent and, so far as observed, their planes were vertical and their strike roughly north and south. There are all variations, from the largest faults to those of microscopic size. For a good example of faulting on a small scale see Fig. 2, Plate I.

The age of the faulting seems to be pre-Keweenawan, and it was probably connected with the fissuring which opened the channels now filled with the diabase dikes. Near the eastern end of the southern range a diabase dike is displaced, but at the point of displacement it is broken up into numerous little branches which indicate that the branching of the dike was due to previous faulting and the fracturing of the rock near the fault.

These displacements brought out one interesting point regarding the relations of the Iron formation and the underlying rhyolite and tuff. In all cases where a dip fault cut across an outcrop of the rhyolite within the Iron formation, the outcrop of the rhyolite was widest on the upthrow side of the plane, thus showing that it widened with depth and therefore that it was not folded down into the Iron formation from above. This condition was seen in several cases, and seemed to establish the relations between the tuffs, rhyolite and Iron formation.

Cleavage:—Cleavage is well developed in many of the rocks, although there is a tendency for fracture rather than flow to occur, owing to the rocks not having been deeply enough buried to cause flowage. In the greenstones all gradations between massive rocks and perfect schists can be found, and there are examples within these rocks of unorientated, partly orientated, and completely orientated crystals. When the condition of complete orientation has been brought about, most of the original minerals have completely disappeared and are now represented by sericite, biotite and secondary hornblende. The rocks which have been so completely mashed as to produce a perfect cleavage are generally much weathered and now almost unrecognizable for purposes of lithological classification. A linear-parallel cleavage,[5] *i.e.*, a cleavage parallel to a line, is often developed in the greenstones, and they part into masses more or less hemicylindrical.

In the rhyolites a megascopic schistosity is developed, but, on account of the nearly equi-dimensional nature of the feldspar and quartz crystals, no great degree of orientation of the crystals is noticeable. In most cases these crystals have fractured without flowing, and although granulation and some recrystallization has occurred, very little parallel orientation has been effected. In the rock sections in which much sericite or biotite has been developed, considerable orientation has taken place.

In some of the slates a good cleavage is developed; and this is particularly well shown under the microscope by some of the phyllites, or slates bearing much mica, which is arranged with the long axes of the plates parallel to one another.

A fracture cleavage is very common in the jaspers and slates. It occurs on a very small scale in the jaspers, in which from one to three sets of parallel intersecting fractures may be seen with the aid of the microscope. There is, according to Leith, a difference of opinion as to whether this type of cleavage, like flow cleavage, is dependent upon a parallel arrangement of the mineral particles.[6] In the slides examined no relation was found between the fracture lines and the arrangement of the minerals, nor is there always any relation between the bedding planes and the direction of the fractures, though they often follow one another. In slide 112 there is a set of fractures parallel to the bedding planes, another set cuts these at 18°, and a third set at an average of 40°. There is also a set of coarser, irregular fractures cutting the bedding planes nearly at right angles. A series of fractures as described above would be developed by stresses applied in a direction normal to the bedding-planes. In Fig. 3, Plate I and Fig. 1, Plate II., examples of fracture cleavage will be found. In the first of these there is illustrated a series of closely spaced fractures in a jasper, and in the second a good example of two parallel sets of fractures intersecting in an acute angle of 37°. Slipping along one set of fractures has produced a lengthening of the rock section in the horizontal direction through the application of pressure in a direc-

[5] U.S. Geol. Surv. Bull. 239, p. 158.

[6] *Ibid*, p. 123.

tion intersecting the obtuse angle at which the fractures intersect. A striking feature about these fractures is that they are almost always filled with quartz, showing that during metamorphic changes the movement of quartz has been a prominent process. With the quartz is often associated sericite, chlorite, carbonates or even a little hematite.

Fracture:—In the greenstones a very common feature is a series of open cracks which often subdivide the rocks into nearly rhombic forms and give them a very rough surface. This fracturing is also seen to some extent in the rhyolites, and some of the apparent conglomerates of this region, composed of oval-shaped fragments of rhyolite lying in a matrix of the same material, were thought, in the field, to be formed by the rounding of these blocks. This rounding would be due to movement of the blocks under shearing stresses, as Smyth and Finlay have shown that some of the pseudo-conglomerates of the Vermilion district have been rounded.[7] Some of the conglomerates thought to have been so formed have proved from a microscopic examination of the matrix to be agglomerates and conglomerates and it is probable that they are all of the same origin.

In the jaspers, fracturing instead of flowage often occurred during the metamorphic changes, and there are all gradations between the two processes. Fig. 9 is a sketch made in the field to illustrate the effect of longitudinal thrusts on bands of jasper embedded in slate. The jasper is much harder and more brittle than slate, and requires a deeper burial to place it in the zone of flow, so that in this case the slate was well within its zone of flow while the jasper was on the border of its corresponding zone. The rock was buried deeply enough to cause some flow, but not sufficiently deep to prevent all fracture, and the result has been that certain bands of jasper have become rolled up and portions nipped off, leaving a pseudo-pebble. Fig. 10 is also a sketch from a field observation to show the result of the isolation of one of these autoclastic fragments.

Metamorphism

Under this heading might be included a description of all those changes which have affected the rocks since their origin, such as folding, mashing, production of cleavage and other structural processes, as well as weathering, cementation and development of new minerals. Since the structural characters of the rocks have already been considered in the previous sections, and the weathering processes can be best described in connection with individual types of rock, this section will be devoted to a brief discussion of the formation of new minerals in the zones of anamorphism and contact metamorphism. The former are produced under the influences of dynamo-regional agents, and the latter by the intrusions of igneous rocks acting on the older rocks in their immediate vicinity. The two types of metamorphism are superimposed upon one another, and the results of the different types are not always readily discriminated. It is also difficult to distinguish some of the minerals which are the products of weathering from those which have resulted from dynamo-regional metamorphism, or from the two combined.

Dynamo-regional Metamorphism:—The greatest changes produced by this type of process are probably the development of quartz from chert, magnetite and hematite from siderite, actinolite from ankerite, and biotite from the iron minerals, while the origin of epidote, zoisite, apatite, dumortierite, garnet and tourmaline cannot always be definitely fixed. Some of the garnet is due to contact action, and it seems reasonable to regard the greater part of the tourmaline as of fumarole origin; but both of these minerals are probably produced in some cases by dynamo-regional influences.

The most interesting mineral formed in this connection is dumortierite, a rare mineral and one never before reported from the Iron formation. On account of its rarity it is given special consideration.

[7] Eng. and Min. Jour., Vol. XXV., p. 629.

Dumortierite:—This is a basic silicate of aluminium, having the composition (Al_{20} Si_{17} O_{44}) or Al_2 O_3, 70.8 per cent., SiO_2 29.2 per cent. Part of the alumina may be replaced by boron, but in this case no analysis for boron was made.

The mineral, as examined, has the following characters: It is orthorhombic. It occurs in distinct prismatic and fibrous crystals, or as irregular grains or plates with terminal faces which in very small crystals can be recognized as pyramidal. In all previous descriptions of this mineral no terminal faces have been recognized. The prismatic angle is over 55°. The cleavage is prismatic and quite distinct. Fractures normal to the prism are very prominent, and a rather imperfect zonary development was recognized in cross section. Optically negative with the axial plane parallel to (010). The acute bisectrix X[8] is normal to (001); X is parallel to c; Y to b and Z to a. The maximum birefringence for blue and violet is .014. Elongation is negative.

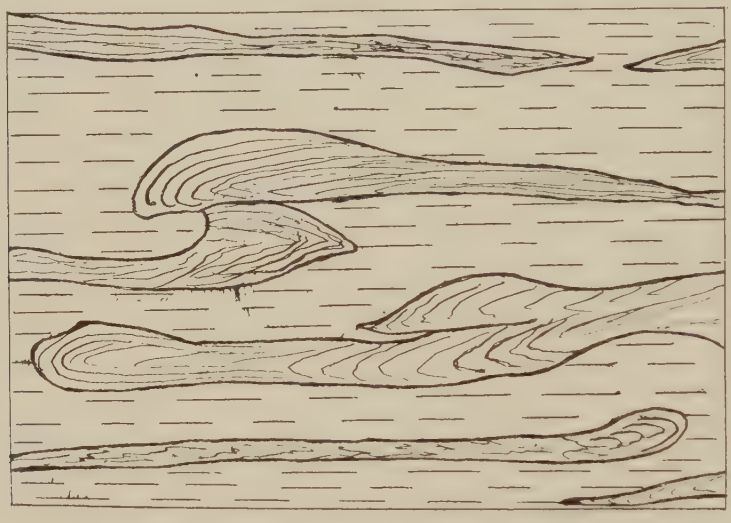

Fig. 9.—Sketch made in the field to illustrate the effects of longitudinal thrusts applied to bands of jasper interbanded with slate. The rock has been sufficiently near the zone of flow to permit some flowage, but not near enough to eliminate all fracturing. Scale 1 inch = 3 feet.

The color is a deep sky blue or a phase of Prussian blue. In thin section the mineral is strongly pleochroic; colorless to deep blue. X is deep sky blue, Y violet or reddish violet, Z colorless to slightly yellow.

The mineral occurs only over a very limited area in the Iron formation on the Miller claims in the northern range, but it was found in two hand specimens from the area, and three thin sections have been examined. In slide 50 it occurs in a very dark bluish magnetite slate, properly called a dumortierite-magnetite slate, which has been highly metamorphosed. The only minerals present in this rock are quartz crystallized from chert, magnetite, hematite and dumortierite. The iron oxides appear to compose about 65 per cent. of the rock, the dumortierite 20 per cent. and the quartz 15 per cent. It is fine-grained, and the longest prism of dumortierite is 0.78 mm. in length. The mineral occurs all through the chert, and its growth is often interfered with by the magnetite somewhat after the nature of the occurrence of minerals in a contact metamorphic deposit. There is, however, no definite evidence in the field of contact action and there are no distinctive contact minerals associated with it, and the mineral

[8] Iddings, Rock Minerals.

is, to all appearances, a product of dynamo-regional metamorphism. A chemical analysis of the rock made by Mr. N. L. Turner, Provincial Assayer, Belleville, gave the following:

—	Per cent.	—	Per cent.
SiO_2	26.72	MnO	Trace
Fe_2O_3	23.19	CO_2	
FeO	19.61	P_2O_5	0.05
Al_2O_3	26.85	K_2O	0.92
CaO	Trace	Na_2O	1.35
MgO	"	Moisture	0.85

The most striking feature of this analysis is the very high percentage of $Al_2 O_3$. The analyses of slates and shales from various sources do not contain, on an average, more than 16 per cent. to 17 per cent. of this oxide, and no other mineral than dumortierite can supply so much of it. As the mineral is secondary, it has evidently derived its alumina from kaolin resulting from a thorough weathering of feldspars, and

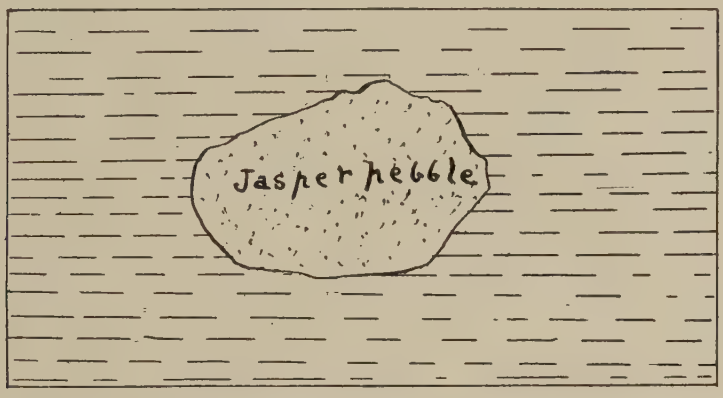

Fig. 10.—Sketch showing an autoclastic fragment of jasper developed by the rolling up and pinching off of a band similar to those in Fig. 9. This illustrates a more advanced stage of the process. Natural size.

a concentration of the products during the formation of the enclosing rock. An investigation of many analyses of clays, compiled by Ries[9], shows that most of these do not contain more than 20 per cent. of $Al_2 O_3$, but that a number exceed 40 per cent. That this is the source of the alumina is supported by an examination of the other two slides, one of which is made from a jasper grading in to a slate (Fig. 2, Plate III), and the other from a banded slate and fine-grained graywacké containing a little magnetite, some siderite partly altered to limonite, much pyrite, some clastic and cherty quartz, apatite, and a good deal of considerably altered unstriated feldspar. The dumortierite occurs scattered universally throughout the section and does not seem to be related to any of the other minerals. It cuts across fractures filled with quartz derived by crystallization of chert from the groundmass. In this section the crystals are not so distinctly prismatic as in the others, and the mineral usually occurs in irregular crystal forms.

The occurrences of dumortierite in other places are comparatively rare. It has been reported from several districts where it was found occurring in granite-pegmatite and in gneiss. It has also been found in a quartz rock. Tourmaline, cordierite and apatite have been found associated with it. In the present case no tourmaline occurs

[9] Clays, Occurrence, Properties, and Uses.

in the dumortierite-bearing rocks, but it is found in small quantities at a short distance from them and in rocks of several types. Apatite is associated with it here.

The other minerals formed by this type of metamorphism do not deserve particular attention beyond an actinolite-magnetite rock which, in one case, was found representing a narrow band of Iron formation. It seems to have been formed from ankerite and chert, which were present in such proportions that all the silica entered into the constitution of the actinolite.

Biotite makes up a large percentage of the phyllites which have been developed where the slates contained a good deal of iron.

Garnets are not common outside of contact zones, and in the one case where they are well developed and their origin is in doubt, they are probably due to contact action, although the intrusive could not be definitely placed. They are associated with a good deal of tourmaline and a little actinolite, and the rather vitrified nature of the slate in which they occur indicates that they are due to a mass of rhyolite-porphyry, which is probably connected with a larger mass considered later than the slate, and which shows as a low outcrop not far away. The slate occurs on the border of a swamp southeast of the Miller claims.

Although tourmaline is widely scattered throughout the region, it is probably due to the after action of the acid magma, and it will be considered under the heading "Contact Metamorphism," which immediately follows.

The development of magnetite from siderite, with a reduction of volume in the iron compound and a transfer of silica to fill the rhombic space formerly occupied by the siderite, is well illustrated in Figs. 2 and 3, Plate II.

Contact Metamorphism:—There are two areas which contain particularly distinct contact results. These are, as already mentioned, situated on the ninth, or "Red" portage of the Red Paint river and on Ste. Marie's lake along the National Transcontinental railway line, about 8 miles west of Wilgar lake. The latter area is locally known as Trombley's claims, because a prospector by that name has staked some claims on the Iron formation there.

In the former of these areas a large batholith of Laurentian granite has intruded the greenstones, green schists and a little lean Iron formation, causing alterations decreasing in intensity for about a quarter of a mile from the granite where they die out. From the greenstones and green schists, garnetiferous schists have been developed and from the Iron formation, actinolite-magnetite-quartz schists. The garnetiferous schist possesses a banded structure with pink to purple garnets developed along certain bands. It is very hard and appears to have been baked. In thin section, a typical contact rock is seen, which has been developed by the contemporaneous development and intergrowth of garnet, cyanite, calcite and blue-green hornblende. No actinolite was seen in this slide, but it occurs in other parts of the same rock. In some cases the garnet completely encloses grains of cyanite.

The actinolite-magnetite-quartz schists show that they have been developed by the crystallization of chert into a mass of quartz crystals fitting closely together and often six-sided, and by the alteration of ankerite and quartz to actinolite. A thin film of iron oxide occurs along the borders of the quartz crystals, and the actinolite needles run along the borders or cut directly across them. Twinning is very highly developed in the amphibole, and one striking feature is the distinct cleavage cutting across the twinning planes at an angle of 20°. This is due to the particular manner in which the section happens to be cut. Chlorite and sericite occur along veins, and in one case a vein of magnetite and actinolite cuts across the section. It appears that this vein has been developed by the alteration of iron carbonate.

As a result of the intrusion, a great deal of pyrite is found in the surrounding rocks, and it is widely disseminated through them. It is largely altered to limonite, which has stained the hills red and has been responsible for the staking of a number of claims in this vicinity by the Algoma Commercial Company, and for the naming of this portage on the river, the "Red" portage.

On the Trombley claims a large mass of diabase has broken into the Iron formation, brecciating it and filling the cracks with pyrite. Along the contact, weathering has been rapid, and Ste. Marie's lake obscures the real relations between the diabase and older rocks. On the east side of this lake a band of very lean Iron formation about 500 feet wide stretches eastward, and in it a good deal of pyrite and some pyrrhotite have been deposited as secondary constituents. These two sulphides are intimately intermixed, but the pyrrhotite is confined pretty closely to the border of the lake, and the outcrop disappears beneath it. The conditions show that the pyrrhotite is closely related to the diabase in some way, and suggest that the pyrrhotite is the direct product of the diabase magma deposited either in the form of a magmatic segregation, as a contact deposit, or as a combination of the two.

The Iron formation has been altered to grünerite and actinolite-magnetite-quartz schists. In thin section the silica is seen to be well crystallized, often into distinct hexagonal crystals, and scattered through it are rhombs of ankerite or siderite partly or completely altered to actinolite. (Fig. 1, Plate III). In the alteration of the carbonate there is often a thin zone of fine-grained magnetite near the border of the rhomb, with the interior filled with a skeletal structure of fine needle aggregates of actinolite, and little needles radiate from the border of the rhombs, giving them a fuzzy appearance. The magnetite crystals are mostly restricted to narrow bands in the quartz, and where they occur the quartz grains are very small, making it appear as if the presence of the magnetite prevented the most complete crystallization of the chert. This feature has probably played a role in preventing the coarse crystallization of many of our fine jaspers, as there seems to be, in most cases, some relation between the percentage of the iron oxide in the rock and the degree of coarseness in the crystallization which has occurred.

The contact effects, superimposed on weathering and dynamo-regional changes, have produced extensive alterations in a rhyolite occurring in this area. Remnants of orthoclase crystals remain in places, but, in other cases, the outlines are indicated by the presence of sericite, kaolin and quartz. Biotite is developed to a considerable extent, as well as a deep bluish-green hornblende, in small crystals, and often in a somewhat irregular radiating arrangement. The hornblende and biotite are intergrown. A good deal of chlorite, epidote and some zoisite have been developed by weathering and contact action, and, in one section, a large number of garnets were found. The latter are intergrown with the groundmass, with quartz, with hornblende, with chlorite, and, in some cases, they penetrate the remnants of feldspar phenocrysts. The zoisite occurs in grains and in long slim prisms. One small crystal of almost colorless enstatite was found. Little apatite crystals are very numerous.

The groundmass has almost entirely recrystallized and there has been a tendency for the quartz to segregate into little bunches of crystals. A fracture cleavage has been developed in the groundmass, and the parallel fractures filled with calcite and sericite. One small vein of lime-soda feldspar, containing a number of grains of epidote, cuts across the section. The materials for this vein appear to have been derived from the groundmass.

The diabase dikes cutting through the Onaman region seem to have had very little influence on the rocks in contact with them, and this condition is surprising when one considers that some of these dikes are as much as 150 feet in width. They have cut the Iron formation without reducing the hematite in their vicinity to magnetite. The only noteworthy contact effect is seen in the large amount of epidote which has been

developed. It occurs in crystallized form in little veins in the vicinity of the dikes or, as may be seen in the thin section, it is widely disseminated through the surrounding rocks as innumerable small crystals.

The absence of more extensive contact effects may be ascribed to the comparatively cool condition of the magma when it was intruded into the older rocks, or to the intrusions occurring at comparatively shallow depth where the accompanying gases and solutions readily volatilized. The contact effects of the Keweenawan diabase in the Nipigon region as a whole vary greatly; as a rule it has had little effect on the surrounding rocks, but in some cases it has produced very extensive alterations.

Tourmaline:—This mineral is widely distributed in the region, and occurs in several types of rock. Some of it may be due to dynamo-regional metamorphism, but it seems more probable that it is the result of fumarole action, occurring as the after effects of the acid magma which formed the rhyolites and rhyolite-porphyries. Tourmaline has rarely been found in extrusive igneous rocks, and this seems natural because the conditions under which these rocks are formed would permit the ready escape of boron-bearing gases. It appears from the field relations of the tourmaline-bearing rocks that the gases which contained boron arose in different parts of the area, mineralizing some of the rocks, and some of these again much more than others. The mineral occurs in rhyolites, in slates, in graywackés and, to a slight extent, in the matrix of the conglomerate. It occurs in the slates of both the iron ranges and in the rhyolite near the southern range. A little is found in the rhyolite lying between the ranges and in the conglomerate on the Miller claims. It is not found in the jaspers, but occurs in the slates of the Iron formation, which contain a good deal of magnetite and grade over into the jaspers.

The age and source of this tourmaline are difficult to establish. That it is later than the rhyolites in one case is evident from a thin section of rhyolite from the southern range, in which it occurs in little grains and prisms arranged along a plane of schistosity where considerable weathering has occurred. It is entirely limited to the plane of shearing. In another case, the secondary nature of the mineral is not so certain. It is found widely scattered through the section in prisms varying in size from 1.17 mm. in length and 0.05 mm. in width, to extremely small dimensions. The crystals are euhedral and have clear-cut edges. They have been greatly dragged and broken by fractures normal to the prism axis (Fig. 3, Plate III). This breaking shows that these crystals were formed before the development of the schistosity evident in the rock, and they strongly suggest crystals of primary origin. They may be primary, but the fact that this rock has the characters of a re-crystallized extrusive and is greatly weathered, goes to show that the tourmaline cannot be definitely regarded as a pyrogenetic mineral, as it may have been introduced by mineralizers. They have not any definite relation to the feldspars as in many other regions, where they are found replacing feldspar crystals.

The only place where tourmaline has been reported as primary in an extrusive rock is mentioned by Iddings, who found it in spherulites of the rhyolite in Obsidian Cliff[10], and he points out that although the mineral is the product of fumarole action, this action may take place either before or after the solidification of the rock. That this mineral in the Onaman region is the product of the fumarole action of the magma which produced the rhyolite, seems to be probable, because there appears to be no other source for it unless it be the Laurentian granite. The distribution of the granite is not, however, so far as can be detected, related to that of the tourmaline. Although tourmaline is more likely to be associated with granite than any other rock, it may be the product of some rhyolite-porphyries or quartz-porphyries, as it has been found in these rocks and in felsites. Weed and Pirsson[11] have found it in the former, and

[10] Bull. Phil. Soc., Washington, Vol. XI., p. 455.

[11] Weed and Pirsson, Bull., 139, U. S. Geol. Surv., pp. 99-102.

Lawson[12] in the latter rocks. A slide from a rhyolite-porphyry lying between the iron ranges contains two small crystals of bluish-green tourmaline, which are, to all appearance, of primary origin. As some of these rocks are regarded as later than the Iron formation, they could supply the boron-bearing gases to produce this mineral in all the rocks in which it is found, and this is the probable source of it.

In the slates the tourmaline crystals are small and are arranged with their long axes running in all directions, thus showing that they could not have been laid down as clastic fragments in the slate.

In the one case where this mineral was found in the matrix of the conglomerate, it forms a few crystals and grains, mostly with rather ragged outlines, and is, in every case, surrounded by irregular masses of pyrite. The latter mineral in some places fills cracks in the tourmaline crystals. It may be noted in this connection that Lawson found tourmaline in a felsite from the Lake of the Woods region, and the crystals of this mineral occurred most commonly around grains of pyrite. The only reason which I can assign for the occurrence of these two minerals together is that possibly the crack or other opening which permitted the penetration of the boron-gases into the rock also permitted the permeation of pyrite-bearing solutions.

In a slate occurring on the border of a swamp a short distance southeast of the Miller claims, tourmaline is associated with numerous pink garnets. The other minerals present are zoisite, epidote, pyrite widely disseminated in little specks, and an aggregation of small actinolite crystals. The slate is hard and close-grained and the mineral associations suggest contact action, even though the individual minerals are not intergrown to the same extent as they are in some other established contact zones. No igneous mass can be seen close to this slate, but about a quarter of a mile away a low outcrop of rhyolite-porphyry was found. It is probably related to the large mass a little farther east, which is regarded as later in age than the slates, and the contact action observed in the slate may be due to a mass of this rock occurring in the immediate vicinity but concealed from view by drift.

There is a considerable variety in the color of the tourmaline in different parts of the area, and there does not seem to be any relation between the type of rock in which the tourmaline occurs and its color. The colors observed vary from nearly colorless to dark brown and blue. The pleochroism noted in the brown varieties is brown to bluish brown for O and almost colorless to bluish-yellow for E. In a bluish-brown variety the colors are bluish and pale reddish-violet, and in a blue variety O is blue and E bluish-brown to bluish-violet.

The Rock Formations in Detail

It is proposed to treat the different rock formations in detail, beginning with the oldest and considering them in order to the youngest. The igneous rocks will be discussed with regard to (1) their distribution, (2) their structural relations, and (3) their petrographical characters; and the sediments in regard to (1) their distribution, (2) their stratigraphic relations, (3) their thickness, (4) their origin, and (5) their petrography.

The Greenstones and Green Schists (Basic Rocks)

The Greenstones and green schists are the most widely distributed of any rocks of the region, and they are equivalent in general characters to the Keewatin basic rocks in many other parts of the continent. Their descriptions correspond closely with those given by Clements for the Ely greenstones of Minnesota, by Coleman and Willmott for the Gros Cap greenstones of Michipicoten, and by Miller for those of the Cobalt region. They form the base through which the other rocks have risen to the surface and upon which they have been deposited. They constitute a complex series of intrusive and

[12] Lawson, Can. Geol. Sur. Rep., Vol. I., 1885, p. 34 c.c.

extrusive origin. They have been subjected to great dynamic influences, which have developed schists from some of them and altered them in so many ways that the individual minerals and therefore the individual rocks are often undeterminable.

The greenstones and green schists are classed together because it is impossible to separate them on a map. Many of the chlorite schists whose origin would otherwise be unrecognizable may be traced with all gradations into nearly massive greenstones. There is, however, no case where the greenstones do not possess a considerable amount of schistosity.

That some of these schists represent mashed sediments or pyroclastic rocks is possible, because their origin could no longer be determined.

Regarding the relations between the greenstones and the later rocks, it may be stated that in no case was any member of the former series found cutting the acid rocks, and the jaspers were never found directly in contact with them except where this relation was the result of faulting. A good example of the latter condition may be seen on the Winter Camp claims, where the greenstone has been greatly brecciated and an infiltration of pyrite in little veins has occurred.

Petrography of the Basic Rocks

Megascopic Characters:—The megascopic characters of these rocks are: a dark to light green color, on account of the presence of much chlorite; a large content of calcite in little veins or in holes due to weathering; and the ellipsoidal or pillow structure. The latter is seen where the greenstones have retained their massive nature sufficiently for this structure to be identified. That this is a distinctively extrusive character is shown by the fact that in the Poplar Lodge region on Lake Nipigon it occurs in association with amygdaloidal and flow-breccia structures in Keewatin rocks, and in the Vermilion district of Minnesota with spherulitic structures. It is very common in the greenstones of the Onaman region, and is found over wide areas. The structure has often been described from other areas, and its origin is regarded as due to the rolling of lava as it cooled and flowed along. The dark streaks separating the pillows consist of fine-grained decomposed rock containing a mixture of iron oxide, chlorite and other products of weathering action, while the pillows themselves consist of more or less schistose greenstone. The pillows vary in size from three inches to four feet in length. Fig 11 is a typical example of this structure.

Microscopic Characters:—Microscopic work on these rocks is unsatisfactory because of the great alterations which they have suffered. A number of thin sections from specimens taken in different portions of the district showed three greatly weathered gabbros or closely related rocks, two of diabase, one of much altered augite-porphyry and several other basic, chloritic rocks too much metamorphosed to be identified.

A thin section of a rock taken as a type of the greenstones without pillow structure showed a diabase of medium grain with saussuritized feldspars giving rise to kaolin and zoisite. Considerable accessory or possibly secondary pyrite, generally altered to limonite or little specks of hematite occurs, and a greenish secondary hornblende, often becoming almost colorless, is frequently found. The latter mineral has weak pleochroism and often consists of fibrous aggregates (*Strahlstein*) with low polarization colors. This type of amphibole is very common in these rocks and represents an alteration product of hornblende. It resembles actinolite in some respects and may be a variety of it. Other minerals present are quartz, zoisite and epidote. These are all products of weathering. In the gabbros, leucoxene developed from ilmenite is very common. The greenstones with pillow structure are very fine-grained, and little information regarding their fabric or their minerals could be obtained from the thin section.

Where any distinction could be made between the rates of weathering of different minerals, the feldspars were found to alter more rapidly than the ferro-magnesian minerals.

Rhyolites and Rhyolite-Porphyries or Quartz-Porphyries (Acid Rocks)

Relations to other formations:—It was impossible to determine whether the line of separation between the basic and acid rocks occurring here was distinct, or whether there was a rather gradual transition from one type of rock to the other. That the greater part of the acid rocks were the distinct successors of the basic rocks is shown

Fig. 11.—Sketch of ellipsoidal or pillow structure in greenstone. Scale 1 inch = 1 foot. (Compare Clements, U.S. Geol. Surv., Mon. XLV., Pl. IV.)

by the fact that the greenstones were never found cutting the rhyolites or acid porphyries, but the porphyries cut the greenstones in many places. The two are often so folded and mixed up together that their relations cannot be definitely

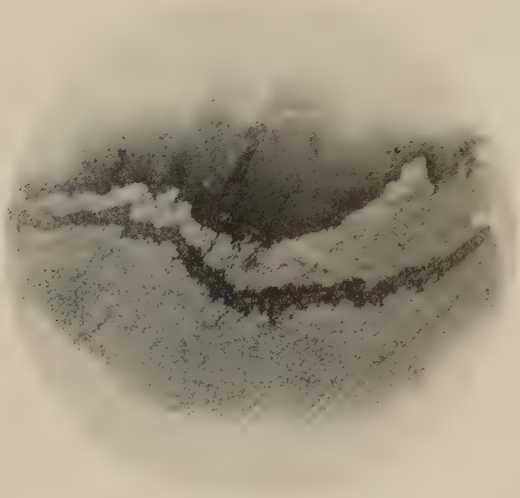

Fig. 1

Fig. 1.—Photograph of thin section 75, showing minor folds developed in a banded slate.
Natural size x 2½.

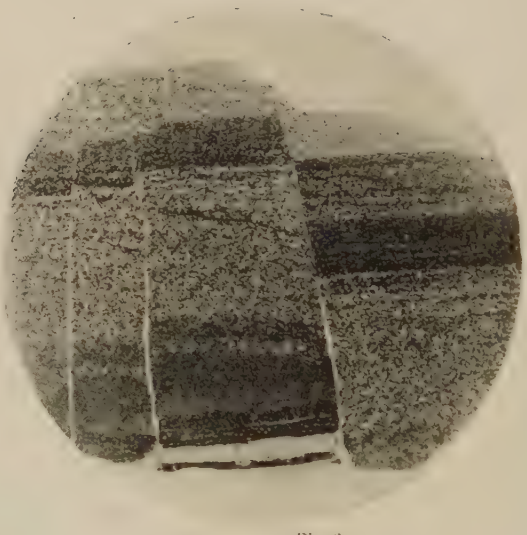

Fig. 2

Fig. 2.—Photograph of thin section 74, showing minor faults in a carbonate slate. The fractures are filled with calcite cement.
Natural size x 2½.

Fig. 3

Fig. 3.—Photomicrograph of thin section 55, showing fracture cleavage in jasper. The fractures are filled with cherty quartz.
Natural size x 35.

PLATE I.

established. There appears to be, in general, less quartz in the acid rocks, which are certainly older than part of the Iron formation, than in those which are to all appearances later. In the field one gets the impression that the line of separation between the acid and basic types is pretty sharp, because the distinction is emphasized by the better preserved texture of the former rocks on account of their greater resistance to weathering agencies.

The great intrusion of Laurentian granite following the close of the Keewatin period, suggests that the granite magmas and the magma from which the later rhyolites and porphyries were derived may have been closely related, the former solidifying at great depths and representing the most acid phase of the magma, while the latter solidified at or near the surface. That there was, however, a considerable differ-

Fig. 12 —Contact between Iron formation and agglomerate on the southern range.

ence in the conditions existing at the time of their formation is shown in the fact that after the peneplanation of the region the two types of rock appear at the surface at the same altitude. One of these possesses the characters of a deep-seated rock and the other those of an extrusive, or of a rock formed at shallow depths. These differences indicate a great time interval or structural change between the time of formation of these two types.

In regard to the relation of the rhyolites to the Iron formation, no case was observed where the two formations were actually in contact. Their relations are illustrated best in the southern iron range, where the rhyolite is found on both sides of the range, though only a narrow band of it occurs on the north side. Here the two formations are always separated by a thin band of tuff or agglomerate. Some narrow bands of rhyolite occur in the Iron formation, but, so far as observed, these bands were always surrounded by a zone of tuffs or agglomerate, which showed that this rock had been

folded in from beneath. Further, the dip faults cutting the formation in several places produce a wider outcrop of the rhyolite on the upthrow than on the downthrow side, thus showing that this rock widens with depth, and as several such cases were observed, the older age of the rhyolite seemed to be established. Similar conditions were observed on the Miller claims in the northern range.

That there are acid rocks later than the Iron formation is shown by the large mass of rhyolite and rhyolite-porphyry which cuts across the eastern end of the northern range. The contact between it and the Iron formation cannot be seen, but the mass stands at a greater altitude than the Iron formation where the latter disappears beneath the drift, and it lies directly across the strike in such a way as to almost completely cut off its extension to the east.

Since we have acid flows and intrusives of both older and younger age than the Iron formation, it was expected that flows would be found interbedded with the sediments. In the field it is impossible always to distinguish between the altered sediments and altered igneous rocks, so specimens were frequently collected from indefinite bands. In no case, however, did these, under the microscope, prove to be igneous, but were tuffs, graywackés and slates. It is nevertheless possible that such bands exist and were overlooked.

Distribution:—Next to the greenstones and the drift, the acid eruptives are the most widely distributed of any rocks in the region. An examination of the map shows that they are closely associated with the Iron formation,—so closely, indeed, that a genetic relation with the Iron formation is suggested. I do not think that such a relation can be proven for them, and the chief reason for their occurring together is probably that, in the folding of the Keewatin rocks, the synclines tended to develop near the junction of the greenstones and rhyolites. There would be a structural line of weakness along this line, and since the folding the Iron formation and rhyolite have been preserved in the synclines. Regarding the relation of the rhyolite, which has been considered later than the Iron formation, it is supposed that it was poured out in the basin over the Iron formation and that it has also been preserved in the syncline.

Petrography of the Acid Eruptives

There are, among the acid eruptives, types which, in individual sections, might be regarded as rhyolites, meta-rhyolites, apo-rhyolites,[13] quartz-porphyries,[14] or rhyolite-porphyries, feldspar-porphyries[14], and some which even approach dacites in composition. There is, however, such a close connection between the different types, and they grade into one another in such a way, that they must all be regarded as different phases of the same magma. The rhyolites differ in different parts of the field in somewhat the same manner as those described by Iddings in the Eureka District of Nevada,[15] *i.e.*, some are characterized by a paucity of phenocrysts, while others are crowded with them, and there is some evidence of variation in the coarseness of the groundmass.

The characters common to more recent lavas have been largely lost by these rhyolites through metamorphism, and some petrographers may object to this use of the term rhyolite for them. The groundmass has recrystallized, the feldspars can no longer be recognized as sanadine and the flow structure has been obliterated in the development of schistosity. On the other hand, textural features, such as their porphyritic characters, re-absorption of the phenocrysts, and the field relations seem to warrant one's considering these as acid extrusives and therefore as rhyolites.

The rhyolite-porphyries, in some places, are with difficulty distinguished from the rhyolites, and probably represent those portions of the magma which have been intruded near the surface or formed in the deeper parts of some of the flows. They show less

[13] Term suggested by F. Bascom, for metamorphosed rhyolites, U. S. Geol. Surv. Bull. 136, p. 38. [14] These terms are no longer used by the U. S. Geol. Surv.

[15] Geol. of the Eureka Dist., Nevada, U. S. Geol. Sur. Mon. XX.

re-absorption of the phenocrysts, larger and more numerous phenocrysts and a slightly coarser groundmass.

The feldspar-porphyries are rare, but one example was found in a dike cutting the greenstones. The description of individual sections will bring out the differences in the types.

Megascopic Characters:—The distinctly rhyolitic types vary from a yellowish-green aphanitic mass to a dark gray crypto-crystalline mass with small phenocrysts of quartz and feldspar. The former type resembles a perfectly silicified rock with the appearance of horn. Both types weather almost white, with small spots of brown ferro-magnesian minerals, and in some cases a thin white coating of something like an efflorescence of magnesium or calcium carbonate may be rubbed off. The fracture is sub-conchoidal, and a platy cleavage has been developed in most cases.

In the feldspar-porphyry type, which was taken from a dike, the rock is dark gray and spotted with numerous dull white phenocrysts of feldspar and a good many of dark mica. It weathers a dirty white and has an irregular fracture.

The rhyolite-porphyry type has, in the hand specimen, a more granular look than the rocks described above and the crypto-crystalline groundmass is crowded with phenocrysts of quartz and feldspar. Some of the quartz crystals are as much as 5 mm. in diameter. The color on fresh fractures gives a sort of a pepper-and-salt effect. Weathered surfaces are white.

Microscopic Characters:—These rocks all have a porphyritic texture and a holocrystalline groundmass, the latter developed by re-crystallization under metamorphic agencies. The groundmass is usually crypto-crystalline, but varies in some cases to micro-crystalline. In almost all cases the phenocrysts have been broken during the metamorphic processes and the cracks filled with sericite or calcite, or both. In some of the rhyolites the crystals have been pulled apart and the spaces between the fragments filled with the regular groundmass, in such a way as to indicate that this process took place during the extrusion and movement of the molten rock. The proportion of quartz, orthoclase and plagioclase phenocrysts varies greatly. In some slides no quartz crystals occur, in some plagioclase and orthoclase are nearly equal, and in others all three may be well represented. The quartz phenocrysts sometimes contain mineral inclusions. The phenocrysts of both quartz and feldspar are very often rounded or gouged by the groundmass (Figs. 2 and 3, Plate IV).

Rhyolite

A thin section of the above mentioned rhyolite, which, in the hand specimen, has the appearance of horn, shows the following characters: The phenocrysts have been greatly crushed, so that now they are represented by irregular aggregates of microcline with quartz from the groundmass intergrown with it along the borders of the crystals. By this intergrowth a resemblance to graphitic intergrowth is produced. The remains of these phenocrysts reach a maximum size of 0.54 mm. by 0.3 mm. Besides these larger ones, there are some small fresh-looking orthoclase crystals, showing Carlsbad twins and not more than 0.108 mm. by 0.08 mm. in size. These may have developed by the re-crystallization of the groundmass.

It has been observed that microcline occurs in the rocks which have been subjected to very great pressure. This would indicate that the microcline twinning may be due to pressure, as some petrographers have suggested.

The groundmass of the above mentioned rock is crypto-crystalline, with portions micro-crystalline, or so finely crystallized that the microscope only shows that it is crystalline by its aggregate polarization. It is composed of quartz, orthoclase and a great deal of very fine scales of sericite.

Tourmaline-bearing Rhyolite

A thin section (17) from the rhyolite underlying the Iron formation on the southern range is interesting because of the large amount of tourmaline it contains (Fig. 3, Plate III). This section contains 14 phenocrysts of orthoclase and microcline, varying in size from 1.97 mm. by 1.18 mm. to 0.5 mm. by 0.3 mm. They do not compose more than 5 per cent. of the rock, and some of them have been greatly mashed and broken. The groundmass is considerably weathered to sericite, and although most of it is crypto-crystalline some portions are micro-crypto-crystalline. Cutting across the planes of schistosity there are lines similar to lines of flow, which have produced a pseudo-banded structure. It is impossible to say whether this banding is a remnant of flow structure or not, as the rock has been so much crushed that this may be a type of false cleavage. A little apatite and iron oxide are present.

The tourmaline in this rock is in euhedral crystals varying in size from 0.98 mm. by 0.098 mm. to almost sub-microscopic. They are scattered through the groundmass and lie in all directions. They have been greatly broken and dragged during the development of schistosity in the rock. They do not seem to have any relation to the feldspars, and do not replace them as tourmaline frequently does in other rocks when it is of secondary origin. This mineral probably composes 1 per cent. of the rock. The color is brown to bluish-brown and the pleochroism strong; O bluish-brown and E pale reddish-violet.

The probable source of this tourmaline is discussed fully uder *Tourmaline* in the section on Contact Metamorphism.

Rhyolite-Porphyry or Quartz-Porphyry

The following characters were observed in a good example (slide 196) of rhyolite-porphyry which occurred along the north side of Castor lake as an apparent intrusive mass of irregular outline. A very finely granular groundmass contains numerous phenocrysts of orthoclase, plagioclase, and quartz. The phenocrysts have been crushed and broken, and the quartz crystals show considerable re-absorption by the groundmass (Fig. 3, Plate IV). The quartz crystals vary in size from 5 mm. in diameter to 0.2 mm. and are not numerous. The largest orthoclase crystals are 2 mm. by 1.4 mm. and they are also not so plentiful as the striated feldspars. A large phenocryst of zonally built plagioclase is 5 mm. by 2 mm. and there are a good many plagioclase crystals which, as a rule, are less than half this size. There is some chlorite and iron oxide representing what appear to have been phenocrysts of biotite. These are not numerous.

The phenocrysts occupy about 70 per cent. and the groundmass 30 per cent. of this rock. Of this 70 per cent., the ferro-magnesian minerals probably compose 3 per cent., the quartz 12 per cent., the orthoclase 20 per cent., and the plagioclase 35 per cent. This composition indicates that the rock approaches a dacite, but the groundmass contains so much orthoclase that it may still be regarded as a rhyolite-porphyry. The groundmass is holo-crystalline, re-crystallized, coarser than that of the rhyolites and composed of quartz and orthoclase, the latter considerably altered to sericite. In the large zonally-built feldspar mentioned above, the index of refraction is greatest in the centre and grades towards the borders. Some of the zones have given rise to white mica by weathering. The facts that the larger phenocrysts have their inner zones of the more sodic feldspar than the outer, and that the groundmass contains so much orthoclase shows that the more basic feldspars were the first to crystallize.

A thin section (32) from a dike of porphyry about two feet wide and cutting the greenstones between the iron ranges, shows that rock to be a feldspar-porphyry. Its composition would be about that of a trachyte-porphyry, but its structure would not justify the application of the term trachyte. There are no quartz phenocrysts, and the groundmass does not contain a great amount of quartz. The phenocrysts are not rounded, and are composed of Carlsbad twins of orthoclase, crystals of plagioclase, some of which are zonally built and composed of albite and anorthite, and one crystal of a

composition between that of labradorite and andesine. Some interesting biotite crystals occur. They are deep brown, colorless, or greenish, the latter color being found where they are considerably altered to chlorite. The shape of the plates is rudely triangular, and they are spotted with little holes around which radiating aggregates of very fine rutile needles have developed as a secondary product. Little crystals of iron oxide are also a product of weathering action and they occur around the border, scattered throughout the crystals, or grouped in little bunches. In the cases where this mineral has lost its color by bleaching, its pleochroism has largely disappeared; otherwise it is typical for biotite.

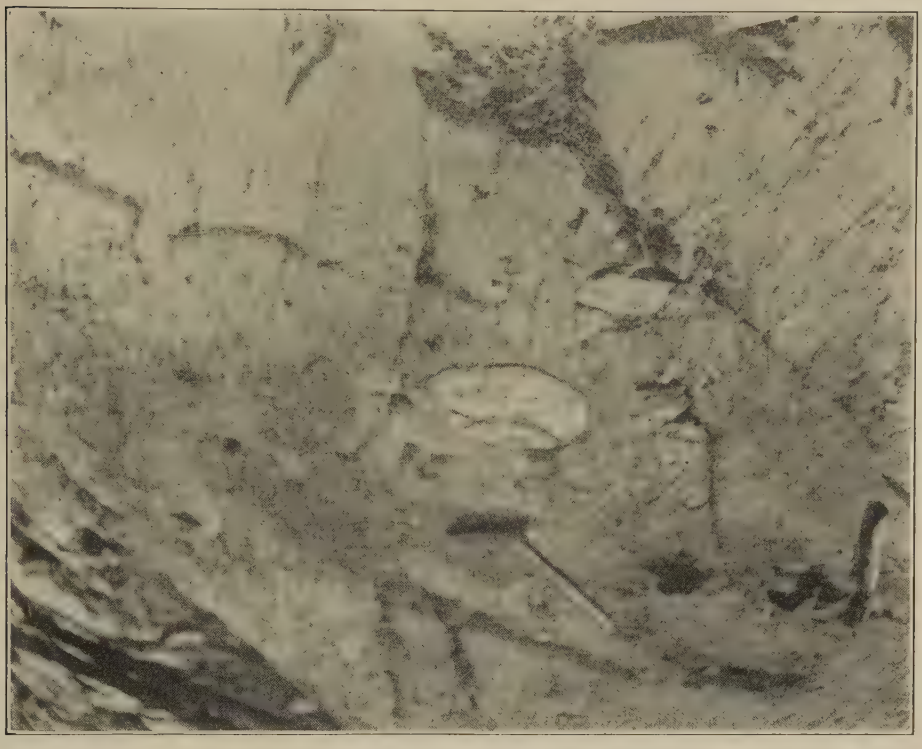

Fig. 13.—Tuff and agglomerate, Johnson creek. (Compare Bayley, Mon. XXVIII., U.S. Geol. Surv., p. 161).

Rhyolite-Tuffs, Agglomerates and Conglomerates

The terms rhyolite-tuff, agglomerate and conglomerate can be properly applied to one rock formation occurring in the Onaman district, because these different types of rock grade into one another, so that no sharp line can be drawn between them. There seem to be all gradations from a pyroclastic rock composed of fine materials or cemented by them, through a sediment composed of coarse and fine volcanic fragments, to a fragmental, volcanic rock with some of the fragments sufficiently waterworn to be called a conglomerate. The predominant part of the formation is composed of coarse and angular volcanic fragments with a matrix which shows that much of the rock was deposited in water and is therefore a true agglomerate.

Portions of these rocks correspond very closely to the agglomerates which Lawson has described from the Lake of the Woods region[16] and the descriptions given by Bayley

[16] Can. Geol. Sur., Vol. I. (1885), pp. 49-54 c.c.

for the Kitchi Schists of the Marquette region of Michigan[17] would also be quite appropriate for portions of this series. Both of these series should be classed as Keewatin tuffs according to the scheme of the International Committee on Nomenclature.

Fig. 14.—Pebbles from the conglomeratic tuff on the Miller claims. (Compare Bayley, Mon. XXVIII., Pl. V., U.S. Geol., Surv.).

At the close of my first period in the field, a portion of these rocks was doubtfully regarded as Huronian and was so laid down on the map accompanying my first report on this area[18]. This article has already been referred to in the Introduction to this

[17] The Marquette Iron-bearing District of Michigan, U. S. Geol. Surv., Mon. XXVIII., pp. 159-162.
[18] 17th Rep. Bureau of Mines, 1903, p. 183.

paper. The true composition and stratigraphic relations were, however, seen later when larger areas of the rocks were located.

Distribution:—These rocks only occur in rather small outcrops, but they are scattered pretty well over the two synclines in which the Iron formation occurs. They begin at the twelfth portage on the Red Paint river below Holliday lake and extend for over a mile along the south side of the river to near the Maple Leaf claims, where they are replaced by the rhyolite and Iron formation. A small outcrop of rock along the north side of the Iron formation on the Height of Land claims, resembles the tuff, and on the southeast side of the greenstone mass which is faulted into the Iron formation on the Winter Camp claims, a small patch of tuff occurs. About half way between the Winter Camp and Miller claims an outcrop projects through the drift along the north side of the syncline, and some of the fragments strongly resemble pebbles in a true conglomerate, while others are very angular. (Fig. 13.) On the Miller claims a small outcrop appears where it has been folded into the Iron formation and another patch along the south side of the outcrop between the rhyolite and the Iron formation is very similar to a conglomerate. Another small outcrop occurs a short distance northeast from the latter and along the same syncline.

In the southern range these rocks occur along either side of the Iron formation for practically the whole length of the syncline, and a few outcrops were found farther south, but the greater portion of them are confined to the basin along which the Iron formation occurs.

Stratigraphic Relations:—In almost every case where these tuffs, agglomerates and conglomerates were found in contact with solid rock, the contacts were with rhyolite and Iron formation. In the small outcrop northeast of the Miller claims an outcrop of greenstone occurred beside the conglomerate and on the Winter Camp claims the tuff lay against the greenstone. In the southern range there are a few doubtful cases, as some of the schists which come in contact with the agglomerate are of uncertain origin. The fact that almost no greenstone fragments occur in the overlying conglomerate shows that it cannot be regarded as a basal conglomerate, such, for example, as that of the Lower Huronian.

The Iron formation overlies conformably this series of rocks and, in a few cases, there is a possibility of interbedding of the two. The relations are such that it is impossible to determine, in some cases, whether the presence of the tuff bands in the Iron formation is due to folding in, faulting in, or interbedding. If they are interbedded, we have a condition here similar to that described by Coleman and Willmott for the Michipicoten district.[19] The outcrops occurring in this way are always very limited in size, and the fragments are not large, so that they may have come from the surrounding lands where they had previously been deposited by volcanic explosions. They could have been transported by water as the fragments of feldspar in the graywackés have been carried. In one case a half dozen of these fragments were observed in a slate lying as narrow bands between thin seams of jasper near the apparent base of the Iron formation of the southern range, and these could not have been folded into the latter formation. They may have originated contemporaneously with the jasper and slate or have been washed in from surrounding lands.

Thickness:—This formation is nowhere very thick. In many places it is impossible to form any conception of what the thickness is, since folding has destroyed all signs of bedding, but where it occurs between the Iron formation and the rhyolite it varies from 1 foot to 50 feet in thickness. It appears to be thicker than that in some places, but the measurement cannot be given with certainty.

[19] 11th Rep. Bur. Min., Ont., 1902, p. 170.

Petrography of the Tuffs, Agglomerates and Conglomerates

Megascopic Characters:—Probably the most striking features in these rocks are the great variation in size of the fragments, the spherical and angular shape of fragments occurring side by side, and the presence of fragments which are almost entirely of one type of rock. There are small areas in which the pebbles are almost all somewhat rounded—some of them, indeed, quite spherical—and as the matrix consists of sedimentary material, this rounding must be due to water action in favorable places along a shore or in shallow spots in a lake. The scantiness of water action on the greater part of the fragments shows that this conglomerate cannot be regarded as marking a great time interval.

The size of the fragments varies from microscopic sizes to those over 3 feet in length. One fragment measured 3¾ feet in length and 1½ feet in width, and another 2

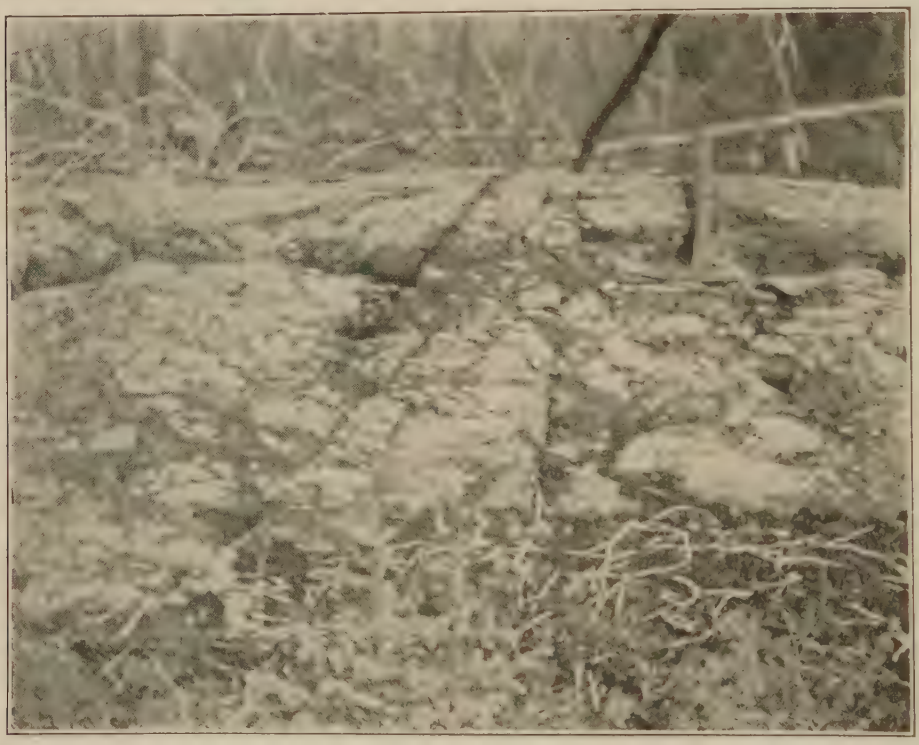

Fig. 15.—Tuff and agglomerate from the north side of the Iron formation on the southern range.

feet by 1¼ feet. A common size is 8 inches long by 3 inches wide, while along the southern iron range the fragments, as a rule, are much smaller, a great many of them being an inch long and a half inch wide (Fig. 15).

The color of the fragments is almost white on the weathered surface and this causes them to stand out above the matrix. They are often of a cherty appearance and harder than the matrix, so that this also causes them to be conspicuous.

The similarity in the composition of the fragments is a prominent feature. They are composed, almost without exception, of rhyolite with usually a very fine groundmass containing few phenocrysts of quartz and feldspar. In one case a small fragment of quartz similar to vein quartz formed a pebble in the conglomerate and in an outcrop of agglomerate one large fragment was identified as greenstone.

The matrix in places has the appearance of rhyolite, while in other cases a brownish mass is speckled with small quartz fragments and shows the characters of a sedi-

ment resembling arkose or graywacké. Portions of the matrix show no textural features, and appear as solidified material of very fine grain and of soft consistency.

Microscopic Characters:—Under the microscope the fragments in these rocks appear to be composed of rocks similar to the fine-grained types of acid rocks previously described. They are often very badly weathered and sometimes too fine-grained for their texture to be determined, but a great many of them are recognized as rhyolite-tuffs.

The matrix has various compositions, even within small areas. It varies from rhyolite to rocks with a composition similar to that of graywacké or arkose. Where rhyolite is the matrix it appears that this rock originally formed the cement for the fragments, while it was in the molten condition, and that flows accompanied the pyroclastic rocks. In the agglomerate at the twelfth portage on the Red Paint river, just below Holliday lake, one can find as cement between the fragments, rhyolite, carbonate and sericite, weathered chloritic and micaceous material like ash, and a rock corresponding in composition to arkose, all within a square mile.

The arkose-like type of matrix is seen in slide 161 and consists of numerous sharply angular to round quartz fragments, with a maximum size of 0.9 mm. by 0.2 mm. There are quartz grains scattered through a mixture of feldspar, carbonate, fragments of the groundmass of rhyolite, and sericitized material. The feldspar fragments consist of orthoclase and plagioclase. They are angular, and, as a rule, a little smaller than the quartz grains. The quartz and feldspar grains are in the proportion of about 3 to 1 in this slide, but in all others examined the feldspar is greatly predominant. The quartz contains mineral inclusions, but no liquid or gas inclusions were seen.

In the rock which is most conglomeratic in appearance, as, for example, the outcrops in the vicinity of the Miller claims, the matrix is composed of fragments of quartz, sometimes angular, but often subangular, and occasionally rounded. These are surrounded by sericite and fine-grained quartz. There is considerable calcite and pyrite, the former scattered irregularly through the section and the latter in small, anhedral masses, often partially or entirely altered to iron oxide. There are few fragments of feldspar. Zoisite crystals are present in one slide. Under the action of pressure the quartz grains have been granulated and partly re-crystallized into interlocking granules. In a few places a fabric resembling that of vein quartz or crystallized chert has been produced by this granulation and recrystallization. In one section (21) a few grains and parts of crystals of brown tourmaline are found. The association of this mineral with pyrite has already been discussed under tourmaline in the section on Contact Metamorphism. It might be repeated, however, that the tourmaline crystals have been fractured and the cracks, in some cases, filled with pyrite, which seems to be always associated with the tourmaline. It is probable that the cracks or pores which permitted the permeation of the boron gases forming the tourmaline, later permitted the infiltration of pyrite. It does not seem probable that this tourmaline is clastic in origin, but from a consideration of all its relations it must be regarded as due to fumarole action of the acid magma.

The matrix above described cements small angular to subangular fragments of rhyolite consisting of a fine-grained re-crystallized groundmass with an occasional weathered orthoclase phenocryst. Slim, needle-like feldspars occur in one of these fragments in a way characteristic of weathered igneous rocks.

Along the southern iron range the matrix of the agglomerate and tuff is made up essentially of broken fragments of feldspar, orthoclase and plagioclase, chiefly the former, with a lesser amount of quartz. The quartz grains have been granulated by pressure and partly re-crystallized. Considerable biotite and sericite are developed between the fragments and along the lines of cleavage. The mica has been bent around the feldspar and quartz fragments during the development of schistosity in such a way

as to produce a resemblance to flow structure. There is little evidence of orientation of the fragments during the formation of cleavage, since they are all so nearly equidimensional. The pyroclastic fragments consist of a fine-grained groundmass, crystallized so that the granules of quartz and feldspar composing it are drawn out into a fine net work of more or less parallel lines. In this groundmass there are a few scattered phenocrysts of orthoclase.

In other parts of this range, the composition of the matrix of the agglomerate and tuff approaches that of a graywacké, and it is hard to distinguish the two rocks, in some cases, except by the presence of the coarser fragments. The graywackés are, as a rule, more extensively weathered.

The Iron Formation

Distribution:—The Iron formation of the Onaman district occurs as outcrops arranged in two bands, so-called ranges, extending nearly east and west across the district and about 2 miles apart. For convenience in description, these ranges have been distinguished as the northern and southern ranges, the latter name replacing the local term Bain claims, used for the southern band in my previous report. The northern range, beginning below Holliday lake, extends across the Height of Land and along Johnson creek nearly to the border of the district, a distance of almost 10 miles. It is not represented by a continuous outcrop, the gaps being of considerable extent. The outcrops are, however, sufficiently close together and the local magnetic influences, where outcrops do not occur on account of the thick coating of drift, are sufficiently strong to warrant one regarding this as a continuous band lying along a syncline. The strike of the outcrops is, in general, east and west, but it varies from 70° to 120°, because of irregularities in the syncline due to faulting and the presence of igneous rocks. The latter have resisted the folding stresses better than the sediments, and have not conformed to the regular troughs which tend to develop in the sedimentary rocks.

The width of the range varies greatly. At the western end the range is represented by a few feet of very lean Iron formation, but near the Maple Leaf claims it widens to nearly half a mile. At this point the area is not, however, occupied by continuous Iron formation, but only by narrow outcrops appearing in green schist, tuff, or rhyolite. Where the range crosses the Height of Land the formation is continuous over a width of 150 yards, but contains a good deal of graywacké and slate, and some rhyolite and green schist have been folded into it.

The outcrop at the divide disappears under the drift and re-appears again on the Winter Camp claims, 2 miles to the east, where the formation occurs as narrow outcrops on either side of a mass of greenstone which has been faulted into it. The formation is again hidden under the drift and three miles to the east re-appears as a considerable outcrop in the vicinity of the Miller claims. Although the range here is broken up by the older rocks near the surface and the formation is excluded from view by the drift which covers portions of this area to a depth of 100 feet or more, sufficient outcrops occur to show that the range can be traced over an area 2 miles long by 1¼ miles wide. The formation here is, on the whole, pretty lean, there being much slate and schist with the jasper.

The southern range is somewhat more continuous and compact than the northern. The most westerly outcrop lies along the south side of Castor lake, where a very narrow band of jasper occurs. There is then a break where drift extends for a mile between this small outcrop and the main portion of the range. It is quite probable that the formation underlies the drift. The main portion of the range is represented by almost continuous outcrops for a distance of two miles, with a maximum width of 700 feet. This range, like the northern one, also contains a good deal of foreign rock in its widest areas.

At the east end of the southern range the Iron formation runs under drift, but local deflections of the compass in a large swamp and the occurrence of a very small outcrop of Iron formation a mile and a quarter east of the main range, show that the range is continuous for at least a mile and a half under the swamp. East of this little outcrop large hills of moraine, composed of sand and gravel, extend eastward as far as the eye can reach.

Outside of the outcrops already mentioned there are two very small patches of the formation occurring to the southeast of the main range, near a large diabase dike. There did not seem to be any evidence that these were related to the dike, but they were found as little ledges of jasper contained in slate and green schist. The Iron formation must have extended over much larger areas than the outcrops now indicate, and now only remains in synclines developed along the original basins which have initiated the downward movement during the folding.

Thickness, strike and dip:—On account of the complexity of the folding in this area, it is impossible to work out the thickness of the Iron formation even approximately. Bands of jasper appear, disappear and re-appear again, and cannot be correlated with any degree of certainty in different portions of the range.

The strike of the ranges is approximately east and west, but locally that of the outcrops of the Iron formation varies considerably. On the Height of Land claims, the strike of the outcrop changes from 80° at the western end to 70° at the east, and on the Winter Camp claims, two faults are responsible for a strike of 70° in the Iron formation. In the vicinity of the Miller claims the strike varies from 90° to 120°, the latter being in a narrow band extending southeast from the main range. The presence of large masses of igneous rock seem to be responsible for the differences in strike here.

In the southern range the general strike is 95°, with local variations as in the small outcrop south of Castor lake.

The dip in the northern range is close to 90°, but towards the eastern end it varies from 55° north to 75° north; in other words, the folds seem to be overturned to the extent of 15° to 35°. (See structure section on accompanying map.)

In the southern range the dip varies from 55° northward to 90°, with 70° north as a common occurrence. This dip is also that of the planes of schistosity in the rhyolite along the southern edge of the Iron formation, and although it represents a considerable overturning of the folds, I think this is only local and due to the presence of igneous rocks. The latter became mashed into schists and did not respond to the folding stresses in the same way as the sediments.

In other Keewatin areas the dip of the Iron formation is, as a rule, more steep than that mentioned above; on the whole, closely pressed together, nearly vertical, folds, with a commonly occurring dip of 70° north, are the results of the great folding which included all of the Keewatin rocks.

Stratigraphic and structural relations:—The Iron formation lies conformably everywhere upon the pyroclastic and sedimentary series previously described. Where these rocks are absent, it may come in contact with rhyolite or green schist, but it has not been observed in contact with typical greenstone, except where the two formations were brought together by faulting. The jasper is separated from the green schist and, as a rule, from the rhyolite, by a slate, usually a phyllite. There seems to be good evidence, as already pointed out in the consideration of the acid eruptives, that the Iron formation has been intruded and to some extent overflowed by the rhyolite-porphyry and rhyolite mass lying across the east end of the northern range. Outside of this one case, there is no definite evidence to show that these rocks have intruded this formation, and there is a good deal of evidence to show that most of them are older than the Iron formation. They are folded into it in several places, and, as already mentioned, the presence of a zone of sediments around the outcrop dis-

tinguishes these masses from those which were intruded. The pyroclastics are frequently found folded and sometimes faulted into the Iron formation and, in some cases, outcrops appear to indicate that some of these are interbedded with the Iron formation. It is difficult to explain some of the narrower bands on any other assumption than interbedding, and if they are interbedded it is impossible to determine whether they were deposited by volcanic eruptions occurring during the deposition of the Iron formation, or whether they were brought in from higher lands by water. As these doubtful bands consist of tuffs, and the fragments are not large, it is possible that they may have been deposited by earlier eruptions on the neighboring lands and transported by water action, as the coarser portions of the graywackés have been carried. In the Michipicoten area Coleman and Willmott considered that volcanic eruptions were contemporaneous with the deposition of the Iron formation, and that the Wawa tuffs were interbedded with the slates and jaspers. It is possible that a similar condition existed in the Onaman district, but there is no definite evidence regarding the matter.

Careful microscopic investigation has failed to reveal any rhyolites interbedded with the Iron formation, but, as previously stated, these might exist and be overlooked, as some of the weathered igneous rocks might very readily be mistaken in the field for weathered sediments.

The Iron formation is not cut by the Laurentian granite on the accompanying map sheet, but on the "Red" portage on the Red Paint river the granite and granitoid gneiss cuts Iron formation of the same age as that on the map. The hornblende-porphyry cuts this formation as a small irregular mass on the southern range, and two diorite dikes cut across it on the Height of Land claims. The Keweenawan diabase dikes cut this same formation in many places, especially on the southern range, and they represent the latest consolidated rocks in this area.

Petrography of the Iron Formation

There are several distinct rocks included in the Iron formation, but they are so related that they must be treated as a unit. These rocks are ferruginous cherts, slates, phyllites, graywackés, actinolite-magnetite-schists, dumortierite-magnetite slates and jaspers, garnetiferous and tourmaline slates. The last four of these types have been treated pretty fully in the sections on Dynamo-Regional and Contact Metamorphism and will not be discussed in detail here.

The relations between the rocks of this formation are such that a band of jasper half an inch in width may occur between bands of slate and graywacké 20 feet in width, and, on the other hand, almost clear jasper bands may reach a maximum of nearly 50 feet. Some of the narrow bands of ferruginous cherts may contain a large percentage of iron, as, for example, one band a few inches wide from the southern range, which was analysed and found to contain 50 per cent. of metallic iron and 23 per cent. of silica.

The banding in the jaspilites, which consist of banded jasper, red or black, alternating with bands of cherty quartz, is often distinctly marked, but the bands are not so clear cut as in the Iron formations of some other regions. Fig. 16 is an example of banded jasper and slate from the Lake Wendigokan district east of lake Nipigon and it is particularly adapted for illustration, because the white slate bands stand out in strong contrast to the red jasper. The slate weathers on the surface to a white shade which is a color characteristic of many of these slates. Another example of remarkable banding is seen in Fig. 1, Plate IV, in which there is represented a magnetite and siderite chert, from the Iron formation on Little Long lake, about 50 miles east of Lake Nipigon. This specimen was obtained through the kindness of Dr. A. P. Coleman, by whom it was collected.

Although many of these bands are clear cut in the hand specimen, they grade more or less into one another in the microscopic section. In many cases there is a gradual transition between cherty magnetite bands, red jasper bands and slate bands, these transitions indicating a gradual change from predominant clastic and minor chemical sedimentation to predominant chemical and minor mechanical deposition.

The Slates

Megascopic Characters:—The slates in some cases possess almost perfect cleavage, and the parting varies from this to an irregular and sub-conchoidal fracture. They are banded with coarser and finer layers, varying in thickness from ¾-inch to a millimetre. In some cases the coarser layers may be classed as graywackés. Their color

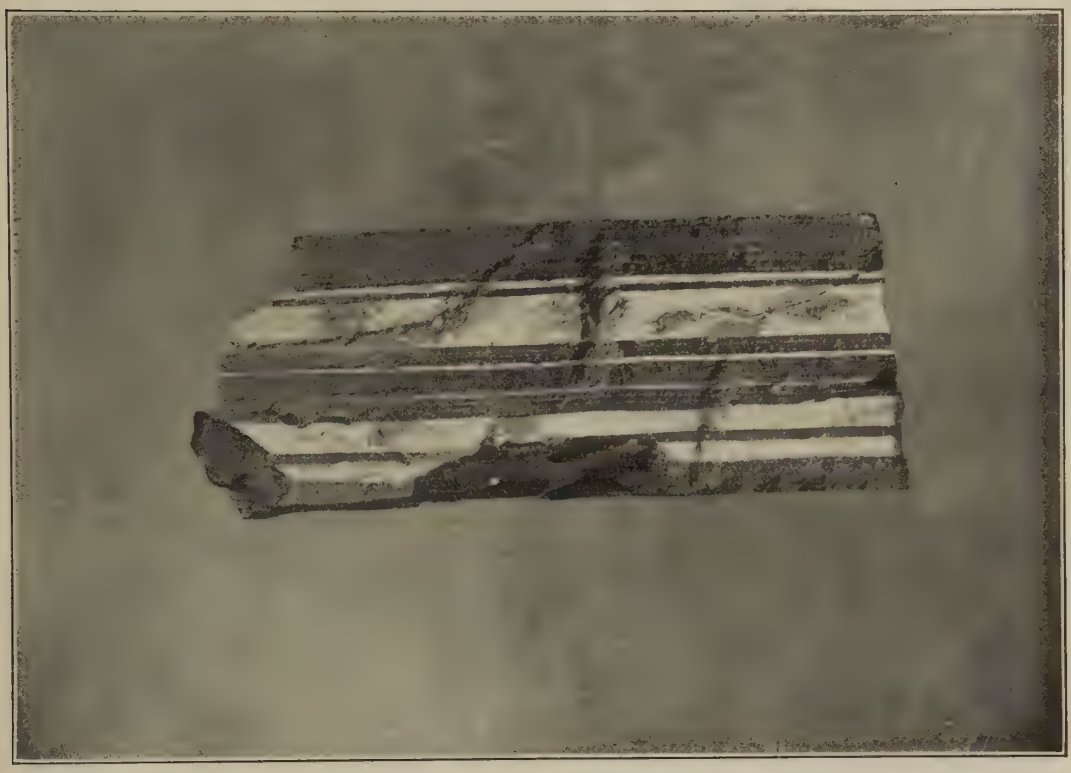

Fig. 16.—Banded jasper and slate from the Lake Wendigokan district.

varies from white to black on the weathered surface, with usually a dark gray to black interior. In some cases the color is greenish from the presence of chlorite along the cleavage planes. Very small veins of silica frequently cut across the rock in all directions and fill small fractures.

Microscopic Characters:—The chief minerals of these rocks are quartz, in clastic fragments, and in the form of crystallized chert, green and brown biotite, sometimes bleached almost colorless, sericite, magnetite, hematite, pyrite, dumortierite, kaolin, small bits of feldspar, iron carbonate, calcite, epidote and sometimes tourmaline and garnet. The biotite often reaches such proportions that the slate should be regarded as a phyllite. The magnetite or hematite may form nearly half the rock, and often the carbonates reach such proportions that the rock may be called a carbonate slate. The tourmaline is rather widely distributed in these rocks, and it occurs as very small cry-

stals lying in all directions, and in such a way that it appears as an undoubted secondary development, and not as a clastic mineral. It is more common in the slates of the northern than in those of the southern range, and it occurs most plentifully near the eastern end of the former range.

Slide 126 is from a phyllite on the Miller claims. It consists more than half of brown biotite in small flakes with their long axes nearly parallel to the cleavage lines, and with a poorly developed false cleavage cutting the true cleavage plane.

Slide 113, from an outcrop of garnetiferous slate southeast of the Miller claims, contains quartz fragments, many of which have suffered re-crystallization around the borders. Sericite, chlorite, kaolin and iron oxide are widely distributed in the section and disseminated pyrite occurs usually in small specks. Small, pink garnets, in euhedral crystals, are associated with a considerable amount of tourmaline in very small crystals. The tourmalines in long slender prisms have been broken by dynamic action. The color of this mineral varies from nearly colorless to brown, and the pleochroism varies with the color. Epidote and zoisite occur in very small crystals and one aggregate of actinolite needles was seen. Although there is not the intimate intergrowth of the individual minerals generally characteristic of contact rocks, this slate, on account of its mineral associations, strongly suggests a contact metamorphic rock. It occurred on the border of a large swamp without any igneous rock supposed to be later, within a quarter of a mile. About a quarter of a mile away, a low outcrop of rhyolite-porphyry occurs, and some related mass may have been responsible for the development of this group of minerals in the slate.

Slide 173, from the slates of the Iron formation on the southern range, is interesting in showing the transition of a slate into a graywacké. There is a good deal of magnetite showing in the section, and it is much more plentiful in the fine slaty layers than in the graywacké bands. There are two things that this difference in the magnetite content of the slate and graywacké might indicate. One of these is that while clastic and chemical sediments were being deposited at the same time, in the case of the slaty material the deposition was so slow that a larger proportion of chemical sediment was laid down than in the case of the coarser clastic. The other condition is that the iron was deposited in the coarser rock and later removed by waters which could more readily circulate in it than in the slate. This section also contains a little tourmaline in very small broken prisms, and one little garnet was seen.

The Graywackes

Megascopic Characters:—The graywackés are monotonous in character, as the rocks are all of dark gray to brown color, and contain small fragments of quartz and feldspar visible to the naked eye. Sometimes a little pyrite is disseminated through the rock. Fractures intersecting at right angles cut these rocks into more or less square blocks, and parting along the bedding planes is frequent. The fracture in some cases is subconchoidal.

Microscopic Characters:—The microscope shows that these rocks are composed of varying amounts of feldspar and quartz. In some cases the quartz fragments form 40 per cent. of the fragments found in the rock, but generally a smaller percentage is present, and the following description is taken as an average example for the district: In the average slide the proportions of the quartz and different types of feldspar were found to be, quartz 25 per cent., plagioclase 10 per cent., and orthoclase 65 per cent. Some of the plagioclase was identified as albite. The relation between the fragments and matrix vary from 25 per cent. matrix and 75 per cent. fragments, to 60 per cent. matrix and 40 per cent. fragments. The fragments are very often little rounded, but, as a rule, much weathered. They generally show more weathering action than the feldspar fragments in the matrix of the agglomerates.

The matrix is composed of sericite, biotite, chlorite, very small fragments of quartz, weathered feldspar, kaolin, and iron oxide. In some places considerable zoisite and epidote occur. Calcite, pyrite, and little crystals of apatite are widely scattered through these rocks. In the development of schistosity, the minerals of the matrix have been crowded and bent around the fragments.

In the study of these graywackés, one is struck by the similarity between them and the cementing material binding the fragments in the tuffs and agglomerates. In fact, it is almost impossible to distinguish the pyroclastics, where the larger fragments are not present, from the graywackés. There is probably no way of separating them but by chemical analysis, and it is doubtful whether this would always distinguish them. Should these graywackés ever be shown to be of pyroclastic origin, it is probable that the slate would prove to be of similar origin, as they grade into one another. In that case the slates would represent the finer tufaceous material of the pyroclastic series.

Fig. 17.—Outcrop of Iron formation rising above the swamp on the southern range.

The Ferruginous Cherts

The ferruginous cherts include the red banded jaspers and silica, or jaspilites of Van Hise, the cherty magnetites and cherty iron carbonates. These three types are all closely related, as they grade into one another, and the latter type is probably the original rock from which the greater part of the other two is derived.

Megascopic Characters:—The jaspilites are crypto-crystalline rocks, with bright red bands of jasper interbanded with and grading into almost pure cherty bands. These bands vary in width from half an inch to almost microscopic sizes. There are frequently bands with fairly coarse silica formed by some of these bands becoming coarsely crystallized, and the glistening surfaces of specular hematite and silica are prominent.

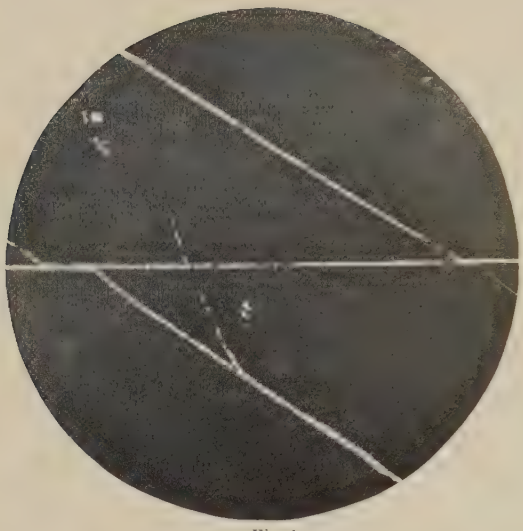

Fig. 1

Fig. 1.—Photomicrograph of thin section 63, showing fracture cleavage in a hematite slate. Elongation has been produced by slipping. The direction of the pressures producing the fracturing and shearing intersects the obtuse angle at which the sets of parallel fractures intersect one another. Natural size X 35.

Fig. 2.—Photomicrograph of thin section 60, showing magnetite crystals in a jasper. The white groundmass is chert and the zones around the magnetite crystals are cherty quartz. This figure illustrates the alteration of siderite to magnetite with a reduction in volume of the iron compound. The rhombs of siderite are replaced by crystals of magnetite, surrounded by a zone of silica. Different stages in the process of alteration may be seen. Natural size X 35.

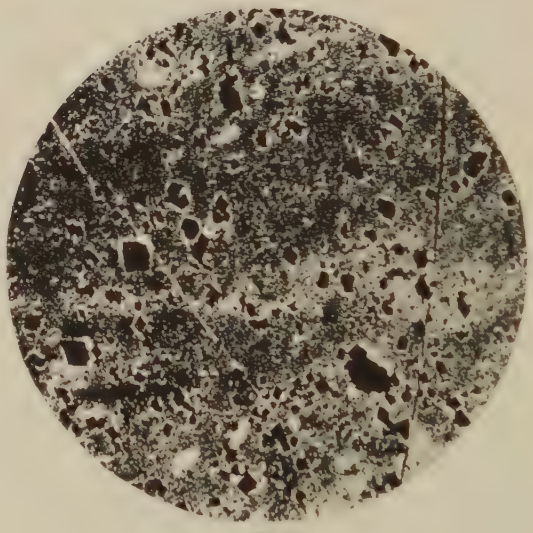

Fig. 2.

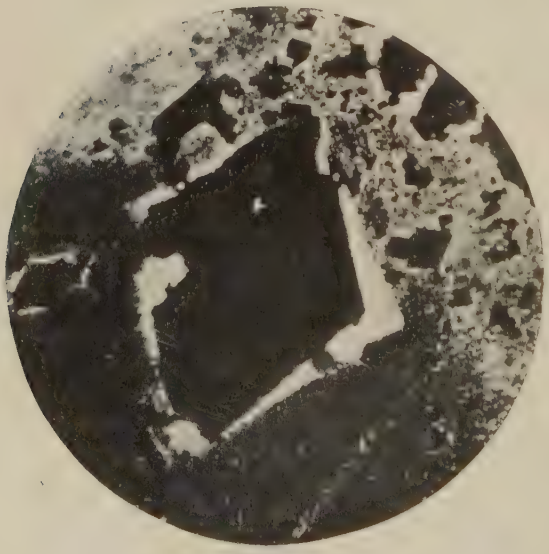

Fig. 3.

Fig. 3.—Photomicrograph of thin section 60. Similar to Fig. 2. Natural size X 225.

PLATE II.

Magnetite may, in some cases, form the principal part of some of the bands, especially where the rock has been subject to great metamorphism. Where the rock is mostly altered to magnetite it is, as a rule, more coarsely crystalline, and the banded structure is not so distinct. Sometimes ribands of slate occur between the bands of jasper and form a very regularly banded rock (Fig. 16).

There are no distinctly banded cherty carbonates in this area,—in fact the carbonates are rather rare here, as the metamorphism has been so intense that they have passed over into the oxides.

The great number of little quartz veins filling fractures all through the jaspers is very characteristic (Fig. 3, Plate I). The fracture is conchoidal to irregular. Some of the hand specimens retain a splendid polish made by the glacier, and others taken along fault planes still have good slickensides.

Microscopic Characters:—Under the microscope the banding of the jaspilites is not so clear cut as in the hand specimen, because in detail these bands usually grade into one another although, in a few cases, a distinct boundary line may be seen. The thin sections are monotonous, in that they present so little variation in mineral content. They are made up of a groundmass of silica crystallized to a greater or lesser degree, with the individual granules of quartz interlocked with one another. The granules usually have irregular outlines unless the crystallization has occurred under the influence of contact metamorphism, when the outlines are, as a rule, clear cut. The more coarsely crystalline silica is found in the bands which are not full of iron oxide, as the iron seems to interfere with the perfect crystallization of the silica, and the fine grained jaspers appear to owe their present condition to the finely disseminated hematite which has prevented the segregation of the silica and its crystallization into coarse granules.

The hematite occurs in little crystals and in specks of sub-microscopic size scattered throughout a silica groundmass. Sometimes these crystals are six-sided but, as a rule, they are somewhat irregular in form. Associated with the hematite are crystals of magnetite, usually euhedral in outline, and varying from almost sub-microscopic size to one-tenth of a millimetre in diameter. These crystals occur scattered all through the fine grained red jasper, or segregated along definite bands.

That much of the magnetite in these rocks is developed directly from siderite is evident from the occurrence of octahedra and other crystal forms of magnetite in rhombic spaces formerly filled with iron carbonate. All stages have been observed in the substitution, from the complete siderite rhombs to the rhombic moulds with a magnetite octahedron surrounded by a zone of cherty silica (Figs. 2 and 3, Plate II). This silica fills the space caused by the reduction in volume of the iron compound, when decarbonation and oxidation occurred with the loss of carbon dioxide. The examples also illustrate the great transfer of silica in these rocks. Siderite is widely distributed through all of the Iron formation rocks, and its alterations can be traced in such a way as to show that it has given rise to the greater quantity of the Iron oxides. Distinct rhombs of siderite, replaced by chlorite, have been found in a slide (No. 56) from the Poplar Lodge region. Calcite is also common, but its relations to fractures makes it appear that this mineral is generally a secondary mineral derived from outside sources, though in some cases it appears to be an original constituent of the rock. Sericite and chlorite very frequently occur dispersed throughout the jaspers, and as the latter approach a slate by an increase in mechanical sediments, green biotite sometimes becomes common. In slide 47, from the southern iron range, there is considerable biotite, parts of it bleached almost colorless. The typical brown pleochroic biotite grades gradually into almost colorless mica. This alteration seems to be due to a weathering process.

Careful observations were made with the view of ascertaining whether clastic quartz occurred in the jaspers. In several cases there were found what appeared to

be clastic fragments, but it is difficult to prove they are such, because during the metamorphic processes the fragments have become partly rounded off and recrystallized. That it is impossible to distinguish a fragment of quartz which has been granulated and partially or entirely recrystallized under dynamo-regional influences, from some granules of crystallized chert, is evident from observations of changes in the quartz fragments in graywackés and the phenocrysts in porphyries. In slates which grade into jaspers one can find a few clastic quartz fragments, and there is no reason why they should not occur in some of the jaspers, but one has no hesitation in saying that clastic quartz is not the source of the great mass of the cherty silica in the Iron formation.

A characteristic feature of the jaspilites is the fine veins of quartz filling openings caused by the development of fracture cleavage. This quartz can be traced to the groundmass of these rocks, and its transfer clearly demonstrates the point which Prof. Leith makes, viz., that in the processes of metamorphism and concentration in the minerals of the Iron formation, the silica is more readily transferred than most of the others. Besides the silica some sericite, calcite, siderite, magnetite, hematite and chlorite are found in these veins, but only sericite, calcite and chlorite are very common. Even these are not so abundant as the quartz in the veins which traverse the jaspers. The magnetite and hematite in these veins are probably due to the alteration of siderite which has been carried in solution.

Genesis of the Iron Formation

There is a great deal of similarity in the Iron formation of all the Keewatin regions, and so much has been written on the subject of the origin of the rocks of this formation, that little can be added to the theories already proposed. In the case under discussion there remains only the application of the observations made in the field to a part or all of these theories In the Survey reports of Minnesota, the Messrs. Winchell have put forth the theory that these iron-bearing deposits are chemical precipitates from a heated sea existing under conditions postulated by the Nebular hypothesis for the early condition of the earth.[20]

At the present time there is a tendency for geologists to depart from the idea of the existence of these special conditions, and to suppose that in Keewatin time conditions were much more as they have been in later time. With this change of view, the time for the first existence of life on the earth has been pushed back to an earlier date, and the leader among the geologists who have been instrumental in bringing about this change of view is Professor Chamberlin.

What might be considered a modified view of the older theories of the origin of the Iron formation is put forth by Leith in an article on the Iron Ores of Canada[21] in which he expresses the opinion that the pre-Cambrian iron deposits owe their origin, in part at least, to hot igneous rocks contributing iron salts directly to the sea by pneumatic waters. Dr. Leith bases his assumptions on the close association of the iron ores with basic extrusive rocks, present in all the systems of rock in which large deposits of banded jasper occur. He further points out that the banded structure of these deposits is unlike any sedimentary rock forming at the present day, and that this structure can be produced by experiment in the laboratory.

From an extensive study of the iron deposits in the Lake Superior region, Irving, Van Hise, Leith, Bayley, Spurr, Coleman, Willmott, and others have shown that there are two chief sources for the iron oxides, these being the cherty iron carbonate and the greenalite. The latter mineral was regarded as glauconite by Spurr, but from a careful study of it, Leith has shown that it is not glauconite, but a hydrous silicate of iron without potash.[22]

[20] N. H. and H. V. Winchell, Geol. and Nat. Hist. Surv. of Minnesota, Final Rept., Vol. IV. (1899), p. 547; ditto Bull. No. 6 (1891), pp. 105, 111.

[21] Economic Geol., Vol. III., No. 4, June-July, 1908.

[22] U. S. Geol. Surv., Mon. XLIII.

In the older reports the writers seemed to regard the supply of the silica as the most difficult problem to solve in connection with these banded deposits. Dr. Leith now considers that the silica is more largely transported than the iron compounds during the concentration of the iron ores. Julien has also pointed out that silica is very largely transported during weathering processes.[23] T. Sterry Hunt has found as much as 21 per cent. of soluble silica in the bog ores of Quebec,[24] and in analyses the writer had made from bog ore in the vicinity of the English river of Ontario, over 8 per cent. of soluble silica was found. Clarke has shown that a large percentage of silica exists in two types of waters, those containing much organic matter and those flowing from crystalline rocks.[25] The soluble silica mentioned above is that which has been precipitated from organic compounds, and Van Hise[26] states that much of the silica in the Iron formation is soluble, so there is some similarity between these two types of silica deposits.

It is well known that chert deposits are the product of organic remains and jaspers are known which contain shells of radiolarians.[27] Other agencies for the transport and deposition of silica are hot and alkaline waters.

From the above observations it is clear that several agencies are adequate to supply silica for the iron deposits. The chief among these agencies are life, and hot, or alkaline waters.

For the solution and transportation of the iron of these deposits from the rocks surrounding the basins in which they were formed, a high content of carbon dioxide in the atmosphere and the action of organic acids have been suggested. From the investigations of the bog ores of Sweden and Quebec, and of the solution and transport of iron in other places, the action of organic acids seems to be the predominant agency at work. T. Sterry Hunt, in the analysis already quoted, found over 15 per cent. of organic acids in the bog ore of Quebec, and Julien has given a great many examples of other analyses which go to show that plants play a very large part in the solution and transportation of iron. In analyses of water from the bog ore district near English river, the writer found that as much as one-eighth of a pound of iron was carried by a ton of water. This was in a region where one would not judge that any great amount of iron could be obtained, because the underlying rocks are Laurentian gneiss, and the drift is very largely composed of boulders and pebbles of granite and sand which have few constituents other than quartz and feldspar. As pointed out in an article on that region, appearing in the present report of The Bureau of Mines, the writer has endeavored to show that the physiographic conditions of the area practically control the solution, transportation and deposition of bog iron. If the land has low relief, so that the streams are sluggish and abundant vegetation exists, organic acids are capable of dissolving large quantities of iron salts. As pointed out earlier in this paper, the physiographic conditions existing in Keewatin time seem to have been very favorable for the development of enclosed basins and unfavorable for well developed drainage. Average basic rock contains about 9 per cent. of iron, and in the presence of plants, volcanic rock such as that so common in Keewatin time, will disintegrate very rapidly. It has been shown that in a few years the lavas of Mount Etna have been brought into a condition suitable for vineyards through the organic action of the prickly pear. Some will argue that the weathering of the rocks is not sufficient to supply the great thicknesses of chemical sediments found in these iron deposits, but Prof. Chamberlin has pointed out that it is probable a selective process was carried on during the Keewatin, when the iron salts were leached out and the coarser clastics left on the land. In Huronian time, to which the great beds of clastics belong, the

[23] A. A. Julien's Monographic paper, Proc. Am. Assn. Adv. Sci., 1879, Vol 28, p. 311.
[24] Geol. of Canada, 1863, p. 511-13.
[25] F. W Clarke, U. S. Geol. Surv. Bull. 330, p. 84.
[26] 10th Ann. Rept. U. S. Geol. Surv., Pt. I., p. 399.
[27] Radiolarians in the Tithonian Jaspers. Eastman's Translation of Zittel, Vol. 1, p. 46.

drainage conditions had so improved that this coarser type of sediment could be carried. Unless it can be shown that the slates and graywackés in the Keewatin are composed of materials supplied directly to the sea by volcanic action, it must be admitted that sufficient basic rock was weathered to supply a very large amount of iron. If an abundance of plant life can properly be postulated for the Keewatin, it seems to me that the agencies at work upon the earth were adequate to supply the iron and silica for these iron deposits. It is true that the conditions existing in early Keewatin time appear, from the evidence of such enormous volcanic activity, to be very unfavorable to life, but the prolonged period of quiet sedimentation which must have occurred during the deposition of the Iron formation would give an opportunity for the development of living organisms. One would also expect that the intrusion of the Laurentian granite would greatly heat the underground water, and that up to the end of the Laurentian time the waters must have been very active chemical agents.

Origin of the Banding

The remarkable banding found in these old deposits is one of the most difficult features to explain. The only deposits forming at the present day which seem quite equivalent to them, are those found around hot springs. In such areas there are deposits which very strongly resemble the banded rocks of the Keewatin, but it is evident that the latter were not deposited by hot springs, because there is no evidence anywhere of the columns and masses which would be formed around the orifices of such springs. During last summer some banded jaspery chert was found filling spaces between fragments of brecciated granite along the contact between the Keweenawan and Laurentian in the Black Sturgeon Lake region, south of lake Nipigon. It could not be proved whether this was a deposit from ordinary cold solutions bearing organic salts, or whether it was related to the diabase sills which are everywhere found intruded between layers of red shale.

The banding in these old rocks has certainly been accentuated by the processes of metamorphism, as one can observe under the microscope how the segregation of quartz and iron oxide into certain bands has taken place. Where the iron is very thickly disseminated through the rock, the crystallization of the silica does not seem to be so coarse and complete as it is in bands where the iron is scarce. This coarser crystallization seems to make the banding more prominent than it otherwise would be. There are, however, clear cut bands of cherty iron carbonate which have every appearance of being original (Fig. 1, Plate IV), and Leith's theory, already mentioned, is the best yet put forth to satisfy the conditions necessary for the production of this banding. Further, the sudden alteration from clastic sediments to beds of well banded jasper, which are in some places as much as 50 feet thick and contain very little clastic material, show that some abrupt change must have taken place in the conditions of deposition, and it seems certain that the deposition must have been rapid or there would be more mechanical sediments in the jasper. The alteration in the coarseness of the mechanical sediments and in their rates of deposition seem to be best explained by changes in climatic conditions.

As to the igneous rocks supplying the iron directly to the sea, there does not seem to be much evidence of that in the Onaman region, unless the acid pyroclastics were the source of the iron. In no place were typical greenstones found in contact with the jaspers except near faults, as a band of slate separates the two rocks. No basic igneous rock was found interbanded with the Iron formation. The jasper in a few places comes in contact with rhyolite, but almost everywhere there is a layer of pyroclastics between the rhyolite and Iron formation, and as a rule slate lies between the jasper and these volcanic fragmental rocks. These pyroclastics seem to have been deposited in water, and there is no iron worth mentioning found in them. If the iron were the direct product of these rocks, one would expect that it would have been laid down as well during the deposition of the pyroclastics as later. There is the possibility, however, of deposi-

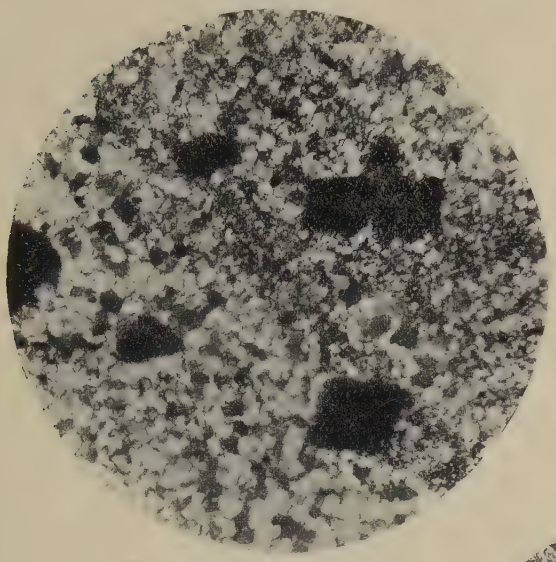

Fig. 1.

Fig. 1.—Photomicrograph of thin section 22. An actinolite-quartz-schist collected near an igneous intrusion. The chert of the iron formation has crystallized and the rhombs of ankerite have partly or completely altered to actinolite. Fine needles of actinolite may be seen all through the rhombs and radiating from their borders. Natural size X 35; crossed nicols.

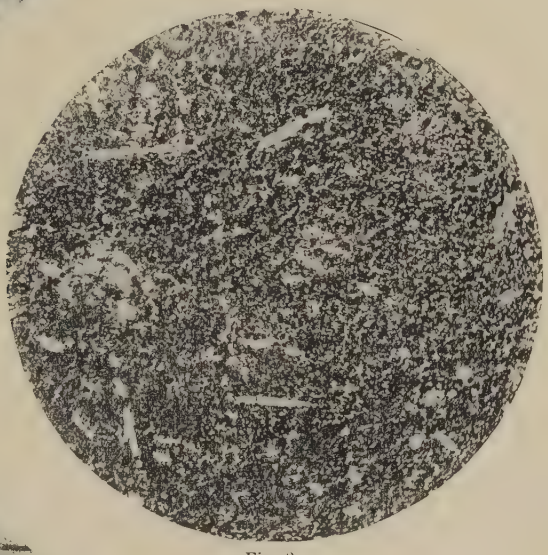

Fig. 2.

Fig. 2.—Photomicrograph of thin section 117. Dumortierite in jasper. The former appears as white crystals, though naturally they are blue. Natural size X 25. With polarizer.

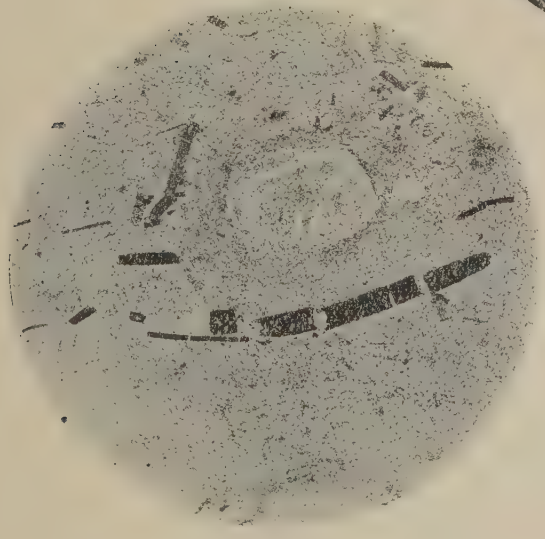

Fig. 3,

Fig. 3.—Photomicrograph of thin section 17, showing tourmaline in rhyolite. A phenocryst of orthoclase occurs near the center of the photo. The tourmaline shows the effects of shearing. Natural size X 35. With polarizer.

PLATE III.

tion having occurred and the iron having been later removed by leaching, because of the coarse texture of the rock. On the other hand, if the iron salts were supplied by weathering action, one would expect a period of time to elapse and a deposition of slate to occur before the waters of the lakes would be sufficiently saturated with iron salts to cause precipitation. If the mechanical sediments occurring in the Iron formation could be shown to be of pyroclastic origin,—and, as previously stated, some of them very strongly resemble fine pyroclastics,—it would then be unnecessary to restrict these deposits to enclosed basins, and the salts might have been supplied by rocks poured into the sea at a considerable distance from this area.

From a consideration of the different theories for the origin of these deposits, the writer concludes that the original rocks were cherty iron carbonate and oxide. No sign of greenalite has been found. The materials were supplied to enclosed basins by weathering action under the influence of plant life, and by heated igneous rocks coming in contact with the waters. These rocks supplied salts of iron and the alkalies to the waters. That cherty iron carbonate was the original rock which gave rise to much of the magnetite and hematite is evident from the wide distribution of this mineral in all the Iron formation rocks, and by the transitions between it and magnetite which may be seen in the thin section. (Figs. 2 and 3, Plate II). That part of the hematite has been deposited as limonite, and dehydrated, is suggested by its very close resemblance to some of our bog deposits of the present day. Under the microscope one can see the gradations from a clastic slate with some iron oxide, into a mixture of hematite and minor amounts of mechanical sediment. The composition and texture of the rock are just what one would expect if some of our bog ores were highly metamorphosed. Since the deposition of these rocks they have been subject to extensive metamorphic changes which have developed magnetites and hematites from the carbonates, and crystallized silica from the chert. The banding has, in some cases, been emphasized, but in others, where concentration of the iron has been considerable, the banding has disappeared.

Economic Possibilities of the Onaman District

The Iron formation of this district does not at present contain "pay" ore. There are many bands of jasper and magnetite which in themselves are rich enough in iron to make ore, but, as a rule, a great deal of schist and slate is mixed with them. There does not appear to have been much concentration, as neither the outcrops nor the drill holes which have been sunk show any bodies of rich ore. The rocks are, as a rule, so hard and close-grained that little percolation of water seems to have taken place No drilling has been done, however, on the southern range, where the best outcrops of jasper occur.

A number of analyses of specimens collected from different parts of the area were made by Mr. N. L. Turner, the Provincial Assayer at Belleville, and a discussion on these follows.

Analysis No. 15. Dried at 100° C.

	Per cent.
Total metallic iron	50.32
Iron in ferrous condition	17.06
Silica	26.85

This analysis was made from a band of magnetite and chert a few inches wide and extending for several rods between bands of slate. A number of other bands such as this could be found in the southern range. It is difficult to trace the longitudinal extension of these bands as they run under the drift and often finger out, but some of them can be traced across good sized outcrops.

Analysis 16. Dried at 100° C.

	Per cent.
Total metallic iron	55.79
Iron in ferrous condition	10.94
Silica	37.10

This analysis was made from jasper collected from an outcrop about 15 feet across and rising out of the swamp. Near the eastern end of the main portion of the southern range (Fig. 18), on the south side of the outcrop, the rhyolite dips under the Iron formation at an angle of 60°, and a large vertical diabase dike cuts across the formation just east of this point, at an angle of 45°. This jasper band is probably more extensive beneath the swamp, and the converging of the rhyolite and diabase tends to form a triangular trough closed at the eastern end. Considering the grade of the ore in this outcrop and the possibility of a basin beneath it, one can regard its vicinity as one of the most favorable spots for drilling on the southern range.

Fig. 18.—Rhyolite dipping under an outcrop of Iron formation.

What appears to be a wider portion of the same band,—it could not be traced continuously on account of drift and irregular folding,—occurs about half a mile farther west, where it is over 50 feet wide and composed of jasper with very little slate interbanded. At this point the total metallic iron content would run from 30 to 40 per cent. At 35 yards west of this wide outcrop the band runs under swamp and cannot be definitely traced to the west, although a band about 100 feet wide, but containing a considerable amount of interbanded slate, occurs west of the swamp.

Analysis 17. Dried at 100° C.

	Per cent.
Total metallic iron	38.83
Iron in ferrous condition	12.9
Silica	50.

This analysis was made from a band of distinctly banded red jasper and magnetite, and represents the iron content of a good deal of the well banded jaspilite, occurring in bands a few feet wide and lying between strips of slate.

From the analyses given above, it will be seen that the southern range does not contain ore which can be worked under present conditions, but it is evident that a considerable amount of low grade material might be obtained by sorting. There is a possibility that drilling might reveal ore in the spot mentioned above, but I should not expect to find any very large body of ore, because of the narrowness of the formation, the apparent shallow depth of the syncline, and the general lack of cencentration of the iron in this area. This syncline appears shallow when compared with the great basins of the large workable iron deposits.

On the northern range diamond drilling has been done, by Mr. R. H. Flaherty, on two of the most favorable looking outcrops (Fig. 19). A hole running at an angle of

Fig. 19. Diamond drill at work on the Winter Camp claims.

60° from the horizontal and driven into the face of the hill was sunk 351 feet on the Winter Camp claims. It was drilled just north of a fault plane, where it was thought a concentration of ore might have occurred. Through the kindness of Mr. Flaherty, it was learned that nothing but jasper was found, and that it varied very little from that occurring at the surface.

Another hole was bored on the western member of the Miller claims, to a depth of 139 feet, at an angle of 52° S. It passed through 31 feet of jasper and then struck what was reported as greenstone, but which was probably rhyolite, in part at least, as this rock dips under the Iron formation near this point. The hole shows that the formation is thin at this spot. A specimen collected from this area as a type of some of the heavier jasper and magnetite samples, was found to be dumortierite-magnetite-slate and jasper, the analysis and complete description of which are given under the

section on Dynamo-Regional-Metamorphism. The analysis shows 42.8 per cent. of iron. There is a large amount of well banded jasper in this northern range, but little sign of concentration has been found. The iron content on the whole is low, but so much of the range is concealed from view by drift that one cannot say, until it is more fully prospected, just what some parts of it may produce. As in the southern range, the eastern end is better than the western, which gives no promise of producing ore.

The Laurentian Granite and Gneiss

The Laurentian system is represented in this area by two outcrops, a small one barely rising above the swamp between the two iron ranges, and a large one along the southern border of the district. The latter extends an undetermined distance southward. The granite was not reached on the northern border, but reports from prospectors state that it occurs about seven miles north of Red Paint lake. This rock is widespread in the Red Paint River region, and along the river it is only broken by a few zones of Keewatin rocks. On the eighth portage on this river there is a large mass of attractive porphyritic granite in which the orthoclase crystals are an inch long.

In the district mapped, the granite has been almost entirely altered to gneiss, and it is similar to the great mass of Laurentian gneiss in the other portions of the Archean shield.

A thin section from the outcrop between the iron ranges showed the following characters: The rock is composed predominantly of microcline, with much smaller content of quartz. There is a small amount of green hornblende. The accessory minerals are biotite in very small quantity, magnetite, hematite and sphene. The biotite is partially altered to hematite, magnetite and chlorite. The apatite occurs as little inclusions in the feldspar. There are about forty small crystals of sphene, which occurs in acutely rhombic cross-sections or in prismatic forms with terminal faces. The largest prismatic form is 0.2 mm. by 0.05 mm. in size. This rock is a hornblende gneiss.

Huronian: Hornblende-porphyry

The hornblende-porphyry found here has been classified as Huronian, because a small mass of this rock was found cutting the Iron formation on the southern range and another outcrop is cut by Keweenawan diabase about two miles southeast. These conditions would thus place this rock between that of the Keewatin and Keweenawan in age. Only these two small outcrops were observed.

The megascopic characters of this rock are: a peculiar pink weathered surface, with dark green blotches an inch long and oval to round in shape, scattered all over the surface; on the fresh surface the rock is seen to be holo-crystalline and finely granular, with a few phenocrysts of hornblende. A few specks of pyrite occur. Some of the feldspar weathers pink and the remainder of the rock is a very dark greenish gray color.

The microscopic characters are shown in thin section 198, in which the rock is composed of green hornblende and oligoclase feldspar. The hornblende is in euhedral and anhedral crystals of three magnitudes, and the fabric is seriate, *i.e.*, there is more or less gradual variation in the size of the crystals. The small hornblendes are, in some cases, completely surrounded by feldspar, and a poikilitic fabric is thus produced. Some of the former mineral is secondary and in places is almost colorless, a characteristic of the changes produced by weathering in these old rocks. This rock might be called a diorite-porphry.

Diorite Dikes

On the Height of Land claims on the northern range, two dikes, 15 inches and 3 feet in width respectively, cut the Iron formation where a trench has been dug across the range. They could only be seen where the formation was stripped. The strike of

the smaller dike is 125°. and that of the larger one 110°, while the strike of the Iron formation is 80°. Their contact effects were seen in the formation of magnetite and granular quartz from the jasper lying close to them. The rock comprising them is badly weathered, and, in the hand specimen, was only identified as a basic rock from the presence of considerable dark mica and other ferro-magnesian minerals. Under the microscope the rock from one of these dikes was found to be so completely altered that no original minerals remained. There is a large number of secondary biotite flakes which are bent and broken, especially where warped around quartz granules. There are numerous patches of calcite, evidently developed from feldspar or hornblende, and associated with the calcite there is considerable free quartz. Much sericite is present in patches arranged as if it had been developed from orthoclase crystals.

Fig. 20. Diorite dike cutting jasper on Height of Land claims on the northern iron range

A specimen from the larger dike was found to be sufficiently fresh to show that it was composed of albite crystals closely crowded together with much secondary calcite and small flakes of biotite. A number of euhedral crystals of pyrite are scattered over the section.

The composition of these rocks corresponds to that of an altered diorite, and it is quite probable that they are of the same age and derived from a magma similar to that which gave rise to the hornblende-porphyry or diorite porphyry described above.

Keweenawan Diabase

It has seemed wise to consider as Keweenawan a series of diabase dikes which cut all the consolidated rocks of the Onaman district. The diabase strongly resembles that of the Keweenawan in other districts, not far removed geographically from the Lake Nipigon basin, which was the scene of great volcanic activity in this period. A

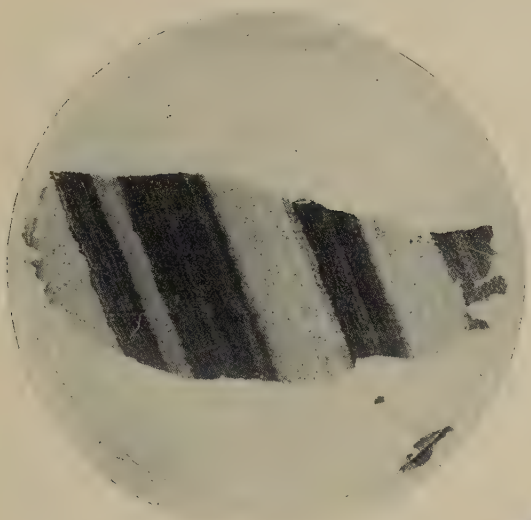

Fig. 1

Fig. 1.—Photograph of thin section 211, showing a banded cherty iron carbonate from the Iron formation on Little Long lake. The dark bands are composed almost entirely of magnetite and chert, the lighter bands of iron carbonate and chert. Natural size X 2½.

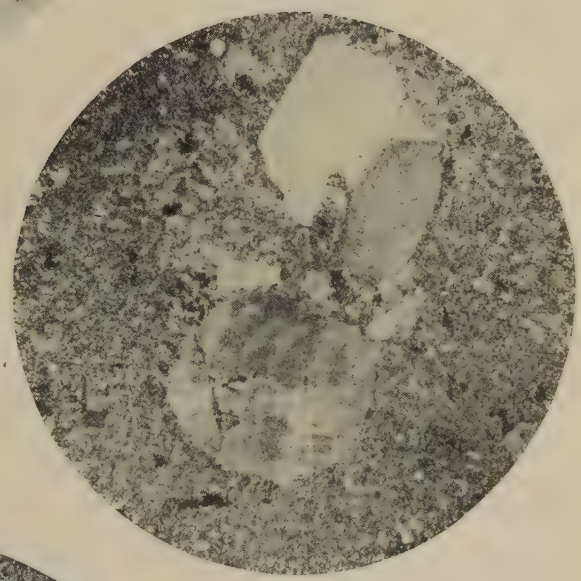

Fig. 2

Fig. 2.—Photomicrograph of thin section 168, showing the re-absorption of a microcline crystal by the matrix. The other phenocrysts are not re-absorbed, possibly because they did not form until after the action on the round one occurred, or because they are of a different composition and not taken into solution so readily. Natural size X 22. Crossed nicols.

Fig. 3

Fig. 3.—Photomicrograph of thin section 196, showing the re-absorptive action of the matrix of a rhyolite porphyry on the quartz phenocrysts. The effect of pressure in producing fracturing in the feldspars may also be seen. Natural size X 22. Crossed nicols.

PLATE IV.

comparison of these rocks with those collected by Mr. W. H. Collins in the Gowganda district of Ontario shows many similarities. For purposes of comparison and the establishment of petrographic provinces it is desirable that geologists give definite descriptions of the diabase supposed to be of Keweenawan age.

These dikes vary much in width, with a maximum of 150 feet. Their strike is in general northwest by southeast and their dip vertical. Their distribution is widespread, as shown by the accompanying map, and it is probable that some of the scattered outcrops which only extend short distances before being lost in the drift should be connected up with one another. There are a few rather irregular masses, but they are doubtless connected below the surface with some of the dikes, as the latter in some cases expand into irregular masses or break up into numerous thread-like dikes. In places on the eastern portion of the southern range little dikes ramify over considerable areas.

It seems probable that these dikes owe their origin partly to the ease with which fissuring occurred during the adjustment of the rocks which must have occurred in the Nipigon basin after or during the transfer of such great quantities of lava toward the upper levels of the earth's crust. The dikes run in a direction which is roughly tangent to the border of this basin. In other parts of the Nipigon region dikes similar to these served as channels by which the diabase magma rose to form the great sills and sheets of the Keweenawan. These dikes may have served a similar purpose in this area, but there are no remnants of such masses to show that such was the case.

The contact metamorphic effects of these dikes have been inconspicuous. In most places the borders of the dike are very fine-grained, but there is often no observable change in the adjacent rocks. The chief evidence of alteration is found in the great amount of epidote developed in some of the slates and gray-wackés of the Iron formation. In these rocks little stringers of epidote occur, and innumerable microscopic crystals may be found in the thin section from rocks occurring within several feet of the dikes.

Megascopic characters of the diabase:—These rocks comprise a medium grained type of diabase. The feldspars are often yellowish on the weathered surface, as if they were partially altered to some mineral like epidote. Pyrite is a rather prominent constituent. The ophitic structure is not apparent, and the appearance of the rock is therefore more like that of gabbro.

Microscopic characters:—Thin section 199 may be taken as a type section of this rock. It is composed of labradorite feldspar, augite and ilmenite. In most cases the feldspar forms lath-shaped crystals, but the ophitic texture is not so well marked as in many diabases. In some cases the augite crystals are almost euhedral, and it is evident that the feldspar and augite crystals must have originated at about the same time. The augite is almost colorless, or shows a pink to light brown tint. It is generally pretty fresh, but the alteration to uralite may be seen along the borders of many crystals. A crystal of augite has one end composed of a green hornblende with an extinction angle different from that of the augite.

In a thin section from another point the augite is largely gone over into secondary hornblende, and many little epidote crystals are developed within this hornblende. Chlorite is common. The feldspars are much kaolinized, and contain considerable calcite as a weathering product. Pyrite forms an accessory mineral in small amounts.

According to a large number of measurements, the proportion of feldspar, augite and ilmenite in these diabases is approximately 55 per cent. of feldspar, 41 per cent. of augite and secondary hornblende, and 4 per cent. of ilmenite. The specific gravity is 2.88.

Pleistocene Deposits

As one ascends the Red Paint river, high sand banks come into view. At the first portage above lake Nipigon a sand and silt plain, the shallow water deposit of a large glacial lake which covered much of the Nipigon region, stands 75 feet above the lake, and a continuation of this plain may be seen between this portage and the next one, five miles up stream. Proceeding towards the Height of Land, these sand banks, which were so prominent on the lower portion of the river, become much lower and just below the divide irregular hummocks of drift occur. These drift deposits show no evidence of a beach along their lower border, nor do they appear to have been covered by water. As the elevation of these hills is not more than 1,050 feet above the sea, and sand plains extending from lake Nipigon up the Sturgeon river south of

Fig. 21. Dry kettle in terminal moraine along Johnson creek.

the Onaman region reach an elevation of approximately 1,090 feet, it seems evident that the water of the glacial lake must have reached a level higher than the hills on the Red Paint river would indicate. It is possible, however, that warping may have caused the difference of level shown here. Considering the absence of beaches, the grading of the sand plain into hills of drift which do not appear to have been under water, and the fact that shallow water deposits of the glacial lake occur at a higher elevation a short distance south than the water line in this area, it is concluded that the ice must have formed the northern boundary of the lake when it stood at its highest level. Before the ice left this region the outlet of the lake must have been changed so as to permit a lowering of its level. It may be that a local advance of the ice deposited fresh morainic materials on the sand plain after the water retreated from this area.

As the writer has pointed out in a previous article[28], there is some difference of opinion as to which of the glacial lakes is responsible for these extensive sand and silt deposits. Prof. Coleman regards these deposits as belonging to lake Warren[29], while Goldthwait[30] and other writers in the United States do not consider that lake Warren ever covered the lake Superior basin. In the article referred to, Goldthwait has given an historical review of the work done on the Abandoned Shore Lines, and from that it would appear that the shores of lake Warren did not extend to the Nipigon basin and that the deposits above described belonged to lake Algonquin.

Around the head waters of the Red Paint river and for several miles down the north side of Johnson creek there is a series of fine terminal moraine hills which stand

Fig. 22. Kettle lake in terminal moraine along Johnson creek.

out distinctly because they have been completely denuded of vegetation by forest fires. (Fig. 5). These moraines mark the position held by the front of the glacier for a long period, and contain many kettle lakes which may have been due to buried masses of ice melting out after the retreat of the main ice-sheet and permitting a slumping of the overlying sand and gravel (Figs. 21 and 22). As many as five of these kettles, or lakes without outlets, have been included in a single photograph (Fig. 5).

On the south side of Johnson creek another group of four kettles appears in a group of hills which represent the position of a lobe of the ice which extended a little in advance of the main mass.

[28] Geology of the Lake Wendigokan Region. Transactions of the Canadian Institute, Vol. VIII., p. 361.
[29] 17th Rept. Bureau of Mines, 1908, p. 167.
[30] Bull. 17, Wisconsin Geol. and Nat. Hist. Survey.

The series of morainic hills occurring in this area extends westward for at least ten miles, with a maximum altitude of 1,200 feet, and eastward as far as the eye can reach. In connection with this moraine only two small eskers were seen. They extend, with serpentine outlines, in a southwest direction away from the foot of the hills. The kames are not prominently developed. The drift is composed of sand, gravel and coarse boulders composed of granite, greenstone and a great variety of other rocks, among which small chert pebbles are very common. Around Red Paint lake and the camps on the Height of Land portage, the drift pebbles are whitened with a coating of calcium carbonate. There are two probable sources for this mineral, viz.: the limestones of the Hudson Bay basin, and the calcite so plentiful in the weathered Keewatin greenstones. As this white coating has not been observed in any such quantity in the drift farther south in the region north of lake Superior, it seems more likely that the limestones are the source of it.

The direction of the ice striations, where noted, is, on the average, 60° (N. 60° E.). On some of the jaspers a glassy polish has remained almost perfect until the present day, and shows how little has been the effect of the thousands of years of weathering to which these rocks have been subject since the ice age.

A Recent Deposit; Travertine

Red Paint lake is fed entirely by springs issuing from the drift beneath its surface, as no superficial stream can be seen entering this lake. The name seems inappropriate for the lake, as the water is a charming, deep blue color. This color seems to be due to the lack of earthy sediments in the water and possibly to the presence of white calcium carbonate on the bottom and disseminated through the water. This white sediment must have an influence on the absorption of the rays of light and in the production of the blue color, because Blue lake, in the southern portion of the district, contains some of this sediment and is also remarkably blue. No other lake in the region possesses a similar deposit or anything like such a blue color. The deposit of calcium carbonate, or travertine, in Red Paint lake is at least 20 feet deep at the southeastern end, as a pole can be thrust down into it to that depth. Around other portions of the lake the deposit varies greatly in thickness and may even be lacking. The creek leaving the lake is so saturated with calcium carbonate that it deposits travertine on the roots and stems of plants along its course, and on the bottoms of the upper lakes of the Red Paint river. As already pointed out in the previous section, the source of this mineral is probably the calcium carbonate found on the pebbles of the drift in the surrounding region, and originally derived from the limestones of the Hudson Bay slope. Were this deposit favorably situated, it might be used in the manufacture of cement, but there is no prospect, so far as can be seen at the present time, of its becoming of economic value. Even the coming of the new railroad is not likely to awaken any industrial interest in a region so isolated and so far removed from the centres of population.

Summary

The Onaman Iron Range district covers about 70 square miles and lies between 45 and 50 miles up the Red Paint river, northeast of lake Nipigon. The Keewatin, Laurentian, Huronian, Keweenawan, Pleistocene and Recent rock systems are represented. The Keewatin consists of an older complex series of basic rocks cut and overflowed by an acid series which are in turn overlain by a thin series of pyroclastics grading into sediments. These pyroclastics are overlain conformably by a banded Iron formation, and in one place this formation seems to be cut and overflowed by the acid rocks. The basic rocks consist of both intrusives and extrusives, and are composed largely of gabbros and diabases. The acid rocks consist of rhyolites, rhyolite-porphyries and feldspar porphyries. The former rocks seem to constitute the matrix of the

pyroclastics in small areas. The pyroclastics consist of tuffs and agglomerates, which grade over into conglomerates with waterworn fragments and a sedimentary matrix. The fragments consist almost entirely of rhyolite. The Iron formation occurs in two bands called the northern and southern ranges, the former extending, as indicated on the accompanying map, almost across the area from east to west. The latter range does not outcrop for more than about three miles, but seems to extend for some distance farther under a swamp. The formation is composed largely of red jasper, often well banded, and magnetite. There are considerable deposits of these minerals, but they are interbanded with a large amount of slate and some graywacké. Some tuffs may also be interbedded with these materials. The formation does not at present contain "pay" ore, though much low grade material exists. There is evidence that the original mineral from which a considerable proportion of the hematite and magnetite has been derived was iron carbonate.

The Keewatin rocks have been cut by the Laurentian granite which now exists as a hornblende gneiss, grading, in places, into granite. The Huronian system is represented only by a couple of small outcrops of hornblende-porphyry and possibly two dikes of diorite which cut the Iron formation. The Keweenawan rocks occur as large dikes of diabase which cut across the district in a general north and south direction.

The drift is thick in many parts of the area, and an interesting series of terminal moraines contains numerous kettle lakes along Johnson creek. The sand plains formed in the shallow water of the glacial lake, Algonquin, may be traced from lake Nipigon up the Red Paint river to the Height of Land near its head waters, where the plain appears to be covered by terminal moraine deposits. The drift pebbles on the Height of Land are often coated with calcium carbonate which seems to have been the source of the travertine deposited by streams feeding Red Paint lake.

Two items of interest here are the occurrence of dumortierite in jasper and slate, and tourmaline in rhyolite and rhyolite-porphyry. The dumortierite is a rare mineral and has never before been reported from the iron ranges. The tourmaline is probably secondary in the rhyolite but it seems to be primary in the rhyolite-porphyry, and its association with this type of rock has not been frequently observed in other regions.